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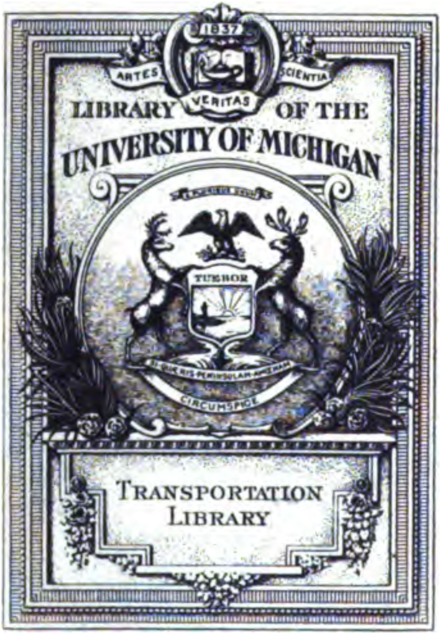

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ELECTRIC RAILWAY HANDBOOK

A REFERENCE BOOK OF PRACTICE DATA,
FORMULAS AND TABLES FOR THE USE
OF OPERATORS, ENGINEERS
AND STUDENTS

BY

ALBERT S. RICHEY, E. E.
CONSULTING ENGINEER, PROFESSOR OF ELECTRIC RAILWAY
ENGINEERING, WORCESTER POLYTECHNIC INSTITUTE,
FELLOW OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

ASSISTED BY

WILLIAM C. GREENOUGH, E. E.

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PREFACE

In the collection and presentation of the material for the Electric Railway Handbook, the aim has been to get together in compact and usable form a large amount of the information which the electric railway engineer frequently requires, but often finds only after an extended search through mechanical, electrical or civil engineers' handbooks or the files of technical journals or proceedings of engineering societies. The field of the electric railway engineer is so broad that such information has necessarily been very much scattered, and progress has been so rapid that a great deal of valuable material has been available only in periodical publications, where, unless held by a good index system, it was soon lost to the operating engineer. The idea of a reference book for the practical electric railway man has been kept in mind, and no attempt has been made to produce a text book, although it is believed that the book may be a useful aid to the student.

It has not seemed wise to include detailed material relating to power plants as such, as this is a field in itself, well covered by existing books, and requiring much more space than is available here. Such matters as the influence of amount and character of load on the capacity and location of power plants and substations are, of course, given due consideration in connection with such subjects as power requirements, energy consumption, feeder layout, etc. In the section on Buildings, the field of the architect has been entered practically only so far as electric railway building problems may differ from others. Other instances may be cited of intentional omissions or very brief consideration of certain matters, such as the elementary treatment of the laying out of track curves, the design of transmission lines, and signaling systems. In the comparatively rare cases where the matters in hand require more extended formulas and data than are here included, the problems are so special and the engineer who is competent to handle them is so well supplied with information that it seems unwise to burden this volume with the material. In short, no attempt has been made to cover the entire field of electric railway engineering, ramifying, as it does, into the special provinces of the civil, mechanical, electrical, chemical engineer and architect. Rather, it has been the aim to present data on the subjects which come up in everyday electric railway practice for constant use by the operating, constructing or designing engineer; a book which may be used by the non-technical manager or operator as well as by the engineer; and a convenient reference book on electric railway practice for those who may be specializing in other or allied lines.

Much material has been gleaned from standard books and publications. Due credit has been given in the text, but special mention should be made of such sources as the *Manual* and the *Proceedings* of the American Electric Railway Engineering Association, the *Transactions* of the American Institute of Electrical Engineers, and of other engineering societies, the *Handbook on Overhead Line Construction* of the National Electric Light Association, the files of the *Electric Railway Journal*, *Electric Journal*, and *Aera*.

A special acknowledgment is also due to the following who have so kindly assisted in furnishing needed information: A. H. Armstrong, M. V. Ayres, J. H. Barnard, E. J. Blair, M. H. Bronsdon, C. L. Cadle, Charles M. Clark, C. L. Crabbs, R. E. Danforth, H. P. Davis, S. R. Dunbar, A. W. French, S. L. Foster, W. G. Gove, Charles Rufus Harte, W. J. Harvie, H. C. Ives, A. St. George Joyce, G. H. Kelsay, Norman Litchfield, Bruce Loomis, W. H. McAloney, Thomas B. McMath, W. S. Murray, George W. Palmer, Jr., F. R. Phillips, Clarence Renshaw, F. L. Rhodes, Ralph H. Rice, Martin Schreiber, Harold B. Smith, W. C. Sparks, Thomas Sproule, C. W. Squier, R. B. Stearns, H. M. Steward, Robert I. Todd. Mr. Walter Jackson has read both the original manuscript and the final proof sheets, and has offered many valuable suggestions.

The book is now presented to its user with the request that he make any criticisms or suggestions for additions which may be helpful in making future editions more valuable in the field. While great care has been exercised in proof reading, it is inconceivable that no errors exist, and notification of any that may be found will be greatly appreciated.

ALBERT S. RICHEY.

WORCESTER, MASSACHUSETTS
February, 1915.

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ELECTRIC RAILWAY HANDBOOK

SECTION I

ROADBED AND TRACK

Location Surveys. The general rough estimate of cost of railroad location surveys in the United States has long been $100 per mile. W. Beahan in "Field Practice of Railroad Location" gives this figure as including reconnaissance and preliminaries, with modifications to $50 per mile in easy prairie country, and $150 in timber country for final located line. W. C. Gotshall in "Electric Railway Economics" states that "the cost of this preliminary field work, by which is meant the salaries and wages and board and lodging of the men and incidental expenses, will vary between $65 per mile of line as a minimum, where conditions are favorable, to $120 per mile of line, as a maximum." Beahan gives costs for five lines of the Missouri Pacific Railway varying from $30.17 to $57.43 per mile, salaries being 60 per cent. and subsistence 17½ per cent. of the total. W. S. McFetridge, referring to some 1400 miles of preliminary lines in West Virginia, Ohio, and southwestern Pennsylvania, gives the total cost per mile of completed survey, including all expenses necessary up to making contracts for the line, as:

	Preliminary	Location	Total	Miles
L.K.R.R.	$25	$74	$99	428
Z.M. & P.R.R.	23	79	102	509
B. & E.R.R.	35	105	140	242
B. & N.R.R.	31	94	125	163

In Ohio, 0.5 per cent. gradients and 4 deg. curves were possible; on other lines, 0.3 per cent. on one division and 1.0 per cent. east bound and 0.5 per cent. west bound gradients on the other divisions were possible, with 8 deg. curves.

Engineering Costs on Electric Railways. The following information as to costs of engineering is from data on a large number of electric railways of various classes as noted.

One hundred miles high-speed interurban single-track construction on private right of way. Engineering $1145 per mile, practically 2½ per cent.

Five miles, chiefly light highway construction along country roads. Engineering $1450 per mile, practically 5 per cent.

Two and one-half miles, largely highway construction, but with some heavy work in crossing swamps. Engineering $1825 per mile, practically 4¼ per cent.

Six miles, largely heavy cross country construction including one very heavy rock cut, several salt marsh fills and two large creek crossings, so that until work was well under way parties were obliged to make detours of considerable length in getting to different sections of the work. Engineering $1650 per mile, practically 3¾ per cent.

Six miles, heavy construction line but largely adjacent to highway, including important viaduct over railroad and river, 40-ft. concrete arch bridge and extensive highway work, part of which was within city limits, necessitating an extra amount of engineering supervision. This line was some distance from the trolley and had poor railroad service, resulting in large team bills. Engineering $1875 per mile, practically 3¾ per cent.

Ten miles, cross country line, moderately heavy construction, largely some little distance from highways, necessitating detours of considerable length in going from one part of the work to another, and resulting also in subsistence bills of considerable amount. Engineering $2075 per mile, practically 5 per cent.

Six miles, highway construction throughout, but involving moderately heavy work, as highway was very extensively improved in connection with work. Engineering $1825 per mile, practically 4¾ per cent. This cost included engineering work on the highway and the percentage is based on the total cost of trolley and highway work.

Three and one-half miles, light cross country work with one important viaduct over railroad where bad foundations necessitated an unusual amount of supervision. Engineering $1750 per mile, practically 4½ per cent.

One and one-half miles, heavy construction, being largely filling and cutting on the water side of a river road. Engineering $1875 per mile, practically 3¾ per cent.

Thirteen miles, moderately heavy construction, partly along highways, partly across fairly open country, requiring much team service. Engineering $1075 per mile, practically 4½ per cent.

Fifteen miles, very heavy cross country construction, including six bridges of considerable span and shifting and reconstruction to State requirements of a considerable portion of highway, necessitating two resident parties whose board was paid, and very extensive use of teams. Engineering $1550 per mile, practically 3¼ per cent.

Three and one-half miles, one-third in city street, two-thirds heavy cross country construction, excellent trolley facilities to either end of the line, but unexpected difficulties in the very heavy rock cut made the work proceed very slowly. Engineering $3325 per mile, practically 4¾ per cent.

Engineering Costs on Transmission Lines. Ten miles, on steam road right of way. Engineering $90 per mile, 4 per cent. Line work only.

Ten miles, chiefly on railroad right of way. Change of plans after work was started very largely increased the engineering cost. Engineering $380 per mile, practically 7¾ per cent.

Six miles, along railroad right of way. Engineering $170 per mile, practically 4½ per cent.

Two and one-half miles, largely along railroad right of way, included two substations. Engineering $660 per mile, practically

7½ per cent. (The last two lines should be properly considered as one, in which case the cost per mile is $315, practically 6 per cent.)

Eight miles, on railroad right of way, with one 1500-ft. span across river. Engineering $175 per mile, practically 6¾ per cent.

Five and three-quarter miles, chiefly on railroad right of way. Engineering $300 per mile, practically 7 per cent.

Fifteen and one-half miles, one-half on railroad right of way and one-half cross country in sections with very poor railroad facilities necessitating a large amount of travel of the parties. Cost very materially increased by incompetence of contractor which practically resulted in taking charge of the work and doing it for him. Engineering $260 per mile, practically 16 per cent.

Engineering Costs in Car House Construction. Capacity 103 45-ft. cars. Reinforced concrete house with bad foundations. Engineering $131 per car, practically 5 per cent.

Capacity 400 45-ft. cars, two-story brick house. Engineering $28 per car, practically 2 per cent.

Capacity 45 45-ft. cars. Engineering $105 per car, practically 3¾ per cent.

Capacity 70 45-ft. cars, brick house, includes also engineering on changes and improvements of considerable extent made in old house. Engineering $96 per car, practically 4¾ per cent.

Capacity 32 45-ft. cars. Metal sides on structural steel frame with concrete walls 4 ft. above ground level, on bad foundations necessitating extensive piling and fill. Engineering $106 per car, practically 5¼ per cent.

Engineering Costs on Miscellaneous Construction. *Reservoir.* Raising old dam about 5 ft., constructing gate house with special intake apparatus, stripping approximately 5 acres, an average of 1 ft. of muck, with some road work, 7 per cent.

Turbine Station Extension. Construction of brick steam turbine station practically 150 × 100 ft. with capacity of 6000 kw. (turbines and boilers) 3000 kw. of which was installed, including also dam 170 ft. long and about 5 ft. high with concrete tunnel intake and discharge system (station was directly on bank of river); included all engineering on the installation of the steam and electrical apparatus, 9¼ per cent. Made very expensive because of great need, resulting in 24-hour days much of the time.

Turbine Station Extension (*2nd*). Brick extension measuring practically 136 × 55 ft. built on above station, and installation of one 4000 kw. turbo alternator, but no added boiler capacity, 4¼ per cent.

Canal. Construction of earth dam with concrete core wall 600 ft. in length, maximum height 70 ft., also widening of about 1000 ft. of canal by taking out prism averaging 30 × 30 ft., 3 per cent.

Gas Main Extension. Laying about 5200 ft. half each of 10-in. and 8-in. cast-iron main in city streets, 3½ per cent.

Power Station Extension. Extending old building 96 × 60 ft. and building foundation for 1500 kw. direct connected reciprocating unit and 1500 kw. turbo generator. Complicated by serious quicksand troubles in the foundations, 5 per cent.

Power Station Extension (2nd). Adding approximately 60 ft. to above power station, driving pile floor so that in future the apparatus foundations can be put in without the necessity of pile driving in the building, practically 3 per cent.

Repair Shop. Tearing down old brick one-story shell and building two-story brick repair shop, approximately 100 × 56 ft., practically 4 per cent.

Paint Shop. Rebuilding and extending old frame paint shop 105 × 45 ft. Old part was maintained in use during the work, necessitating unusual amount of supervision. New portion had to have pile foundations which had to be very carefully watched to see that old buildings in the vicinity were not injured, practically 7¾ per cent.

Substation. Brick substation approximately 100 × 30 ft., including the installation of three 450 kw. frequency changers. Complicated at first by title troubles which necessitated complete revision of plans after their first completion and later by discovery of subterranean stream requiring much attention in its care, practically 5½ per cent.

Landslide. Driving 500 ft. of 4 × 6 in. drifts into a treacherous mixture of ochreous clay and gravel. This work was prosecuted by the superintendent of the plant, who was thoroughly familiar with soft ground working and who had a very efficient force which required very little attention, practically 1½ per cent.

Water Power Plant Improvements. Construction of four 8 × 12 ft. motor-operated head gates with concrete settings. Two penstock gates, one 16 × 30 ft. and the other 11 × 14 ft. with operating motors, installation of approximately 500 ft. of 96-in. steel penstock and 96-in. stand pipe 60 ft. high on concrete foundations which had to be built in 16 ft. of water flowing at such speed that a diver could barely stand against it, practically 5¼ per cent.

Right of Way. Crandall and Barnes in "Railroad Construction" (1913) state that prices at which land can be purchased for railroad purposes will be from one to two times the market value in cities, and from one to four times in the country, it being generally recognized that higher prices are justifiable, partly on account of the greater value of the land for the special purpose and partly on account of the lower value of contiguous lands in consequence of their proximity to the road. The latter reason is not so likely to apply in the case of an electric railway.

Clearing and Grubbing are sometimes lumped together with grading in a contract. Specifications for clearing should require the removal from right of way of all trees, brush and other obstruction to grading, except as reserved; brush and other refuse should be burned or otherwise disposed of, but timber should be saved in the form of saw logs, cut into cord wood, or made into ties, as specified; tops of stumps under embankments should be at least 2½ ft. below grade; the removal of stumps and roots (grubbing) is usually required over all places where excavation occurs and between the slope stakes of embankments less than 2½ ft. in height. Payments for clearing and grubbing are made usually by the acre or square of 100 ft. on a side, or fraction thereof, actually cleared or grubbed, but the removal of isolated trees or buildings is often separately contracted for.

Classification of Grading. Too minute classification gives opportunity for dispute and litigation as the percentages of the different classes are usually estimated, not being susceptible to exact measurement. The American Railway Engineering Association (Manual, 1911) gives three classes (solid rock, loose rock and common excavation) for ordinary use, but recognizes the necessity of special classes, clearly defined, in some localities. The Manual defines the three classes mentioned, as follows: "Solid rock shall comprise rock in solid beds or masses in its original position which may be best removed by blasting, and boulders or detached rock measuring 1 cu. yd. or over. Loose rock shall comprise all detached masses of rock or stone of more than 1 cu. ft. and less than 1 cu. yd., and all other rock which can be properly removed by pick and bar and without blasting, although steam shovel and blasting may be resorted to on favorable occasions in order to facilitate the work. Common excavation shall comprise all other materials of whatsoever nature that do not come under the classification of solid rock, loose rock or such other classification as may be established before the award of the contract." Common excavation may be subdivided into loam, strong, heavy soils and stiff clay or cemented gravel in estimating the cost of excavation with men and teams, but a steam shovel will handle all of these and even loose rock at about the same cost. Hardpan, or earth which cannot be plowed with a four-horse team, is now generally omitted from classification on account of the difficulty of separating it from common excavation.

Shrinkage must be allowed for both in figuring on the distribution of the earth and in making the embankments, and the American Railway Engineering Association (Manual, 1911) recommends the following: "For green embankments, shrinkage allowance should be made for both height and width, as follows:

For black dirt, trestle filling	15 per cent.
For black dirt, raising under traffic	5 per cent.
For clay, trestle filling	10 per cent.
For clay, raising under traffic	5 per cent.
For sand, trestle filling	6 per cent.
For sand, raising under traffic	5 per cent.

Solid rock will swell about 70 per cent. from cut to fill.

On account of the uncertainty in shrinkage percentages, it is customary to measure earthwork in excavation, but the method of measurement should be clearly specified.

Pay Quantities. Where the material taken from the cuts is used in making the fills, the price paid for excavation includes hauling and placing in the embankment, and this should be done as far as is practicable. The cost increases, however, until the economic lead is reached, where the cost is such that it is cheaper to waste at the cut and borrow at the fill. Beyond the economic lead, the yardage will then become the sum of the remaining cuts and fills (plus shrinkage).

Overhaul. When a limit is set for "free haul" or the maximum haul at the contract yardage rate, a definite additional price per cubic yard per station for overhaul is allowed. The definition for overhaul adopted by the American Railway Engineering Association requires the limit of free haul to be fixed so as to include the grade point and balance the cut on the one side with the fill, plus proper shrinkage allowance, on the other. All material within this free haul limit is omitted from further consideration. The distance from the center of gravity of the remaining excavation to the center of gravity of the resulting embankment, less the free haul, is the overhaul. When the haul is over runways laid out by the engineer from borrow pits or to waste, the overhaul is one-half the round trip distance, less the free haul. To calculate the overhaul, find the free haul limit by adding the yardage each way from the grade point, allowing shrinkage for the fills and keeping the quantities balanced until the free haul limit is reached. This will require using plusses with the corresponding yardages for the final result. Beyond this free haul point in the cut, multiply the yardage of each volume by the distance of its center of gravity from the near end of the free haul limit, add the products and divide by the corresponding yardage for the overhaul at the cut end. Find how far this material will extend in the fill and determine the distance of its center of gravity from the near end of the free haul limit as above. The sum at the two ends will give the total overhaul. For heavy work, this method is preferable to a graphic one as being more accurate, unless an inconveniently large scale is used.

Mass Diagram. A simple method of determining the most economical distribution of the material is by means of the mass diagram (or Bruckner's curve). As described by Crandall and Barnes in "Railroad Construction," the mass diagram is constructed by starting at the left or zero end of the profile or other convenient point, say one past which no material will be transported, and adding the yardage algebraically, station by station, allowing for shrinkage on fills. The totals are plotted at the corresponding stations, or plusses for grade points, and a smooth curve drawn through the points thus found as in Fig. 1. Straight lines joining the points would mean that the yardage increments were assumed proportional to the distance.

This method of construction gives to the curve the following properties:

(*a*) An upward inclination of the curve from left to right indicates excavation, a downward inclination, embankment, and maximum and minimum points, grade points. Thus (Fig. 1), *A'B'* indicates excavation, *B'G'*, embankment and *B'* and *G'*, grade points.

(*b*) Cuts and fills balance between the points of intersection of any horizontal line with the curve, leads being to the right where the curve is above the line and to the left where it is below. Thus, the cut from *D* to *B* will make the fill from *B* to *E*, and that from *F* to *G*, the fill from *G* to *E*.

(*c*) Since the cut *BD* makes the fill to *E*, the last of the cut at *D* is moved to *E*, a distance *D'E'*, while the last of the cut from *F* is moved a distance *F'E'*. Equal distances will give the minimum average lead for the fill, as this allows taking the material for each part of the fill from the nearest point. Hence in making a fill from adjacent cuts, or in utilizing the material from a cut in adjacent fills, the minimum average lead is found by raising or lowering the horizontal closing line until the adjacent intercepts are equal.

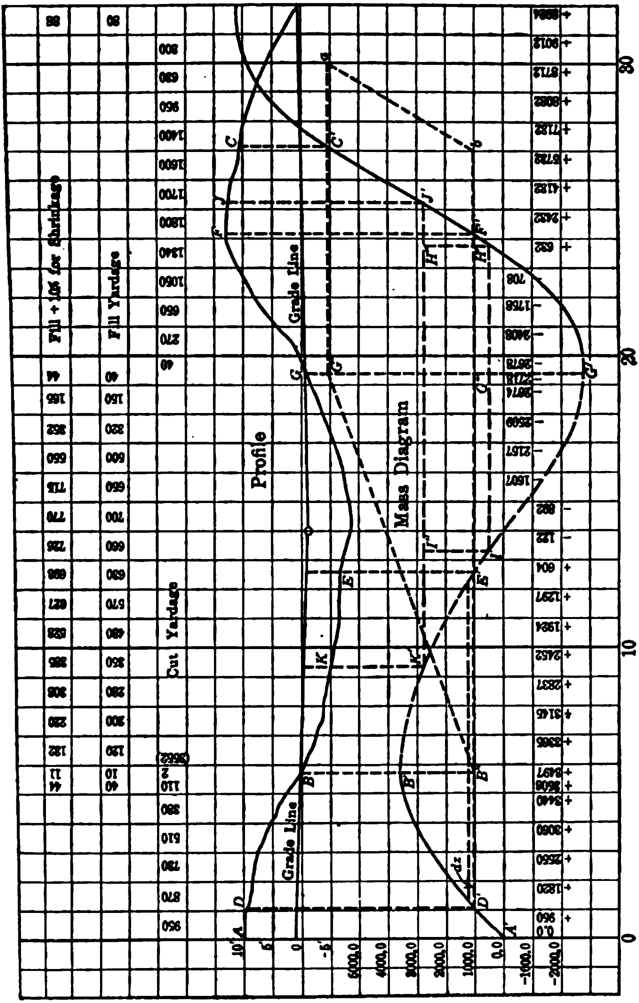


FIG. 1.—Mass diagram.

(*d*) The area between the curve and an intersecting horizontal line will be the product, lead times yardage, for the material between the two points of intersection. For since by (*c*) the material in the cut, *e.g.*, from *B* to *D*, will just make the fill from *B* to *E*, the material represented by the increment dz to the ordinate at *D* must be moved from *D* to *E*, a distance $D'E'$, giving for lead times yardage the area $dz \times D'E'$. Similarly for the other increments giving the total area, lead times yardage as stated above. If area be divided by yardage, the quotient will be the average lead for the portion taken. The yardage for any cut or fill (not containing partial sections) will be the difference of the ordinates at the ends. Hence to find the average lead where the material from a cut is utilized in making an adjacent fill, or *vice versa*, find the area between the closing line and the curve by planimeter or by Simpson's rule and divide by the grade point ordinate or total yardage. In the case of side-hill work, *i.e.*, both cut and fill between adjacent sections and no grade point, only the difference of quantities is used. The balanced quantities in each length are thus ignored. The lead for this material will depend upon the longitudinal and transverse slopes; it will generally be small and can be neglected without serious error. To find the average lead for all the material, including the side-hill work, add to the area found from the mass diagram the product of the balanced yardage or side-hill work by its lead and divide by the total yardage.

The total yardage for the cut *AB* (Fig. 1) is 3552, while the maximum or grade point ordinate at *B* is only 3506 less by 46 cu. yd. If *D* be taken at *sta.* 1 + 08, $D'E'$ will be 1020 above the zero line and the area $D'E'B'$ will be 1,868,700 cu. yd. ft. Adding 46 × 10 for the side-hill product, 10 being assumed for the lead,

Total area = 1,869,160
Total yardage = 3,552 − 1020 = 2532
Dividing, 1,869,160/2532 = 738 ft.

If the side-hill work be omitted,
1,868,700/2486 = 752 ft., average lead.

If the side-hill lead be omitted,
1,868,700/2532 = 738 ft.

The maximum lead, $D'E'$, = stas. [12 + 50 − (1 + 08)] = 1142 ft.

If the material from *C* to *F* is to be wasted uniformly along the fill, *GB*, draw the horizontal $C'G''$ and join $G''B''$. The area $C'G''B''F'$ divided by the ordinate $G''G'''$ will give the average lead. If this material is to be wasted at the grade point, *G*, divide the area $C'G''G'''F'$ by the yardage $G''G'''$ for the average lead. If wasted on the side at a constant lead, aC', draw the horizontals, aC' and bF' and the curve *ab* for the yardage lead area.

To find the overhaul from the mass diagram, draw the horizontals giving the greatest lead or haul and the free haul; the distance between them will give the yardage for overhaul; draw verticals through the ends of the free haul line to meet the maximum haul line. The sum of the areas between these verticals and the mass diagram curve will give the overhaul product, lead times yardage. If the overhaul is required, divide the overhaul product by the overhaul yardage. Thus in Fig. 1, for the cut *GJ* which would make the fill to *K*, *J'K'* gives the greatest haul, *H'I'* the free haul, *H'H"* or *I'I"* the overhaul yardage and the sum of the areas, *H'H"J'* and *I'I"K'*, the overhaul product.

Handling Earthwork. The following figures on cost of handling earthwork, except where otherwise credited, are taken from Crandall and Barnes' "Railroad Construction" (1913).

Loosening. All materials excepting possibly sand require loosening for shovels or scrapers and it will often be economical to loosen even sand, especially for shoveling. Loosening is commonly done with picks or plows, but explosives may be used to advantage under some conditions. A man with a pick will loosen about 15 cu. yd. of stiff clay, or cemented gravel, 20 of strong, heavy soil, or 30 of common loam, per 10-hour day. With wages at 15 cents per hour, these quantities give the following costs for labor, except foremen, for loosening with picks:

Stiff clay or cemented gravel..........	10.0 cents per cu. yd.
Strong, heavy soils..................	7.5 cents per cu. yd.
Loam.............................	5.0 cents per cu. yd.

A two-horse team with plow and driver and an extra man to hold will loosen about 250 cu. yd. of strong, heavy soil per 10-hour day or about 400 of ordinary soil. With very hard material requiring a pick-pointed plow with two teams and an extra man to ride the beam, about 180 cu. yd. can be loosened. With wages at $3.50 per day for team and driver and $1.50 for man, these data would give the following costs for labor, except foreman, for loosening with plows:

Stiff clay or hardpan.................	5.6 cents per cu. yd.
Strong, heavy soils..................	2.0 cents per cu. yd.
Loam.............................	1.25 cents per cu. yd.

Shoveling. Earth may be cast short distances with shovels, the cost being about the same for limits of 5 to 10 ft. horizontally or 4 to 7 ft. vertically. For somewhat greater distances it may be recast, the unit cost being about 80 per cent. if a platform or other suitable bed is provided from which to shovel. This is frequently done in taking material from a pit too deep for one cast. Platforms are also often used in mine tunneling and might well be used in cuts when the material is broken down from a face. Shoveling is also required in loading wheelbarrows, carts, wagons or cars for transporting longer distances. The material should be thoroughly loosened and often a second plowing will be more than repaid in the reduced cost of shoveling. The quantity loaded per man will depend upon the material, the extent to which it is loosened, the height to which it must be raised and upon so proportioning the gang that the shovelers will not have to wait for either material or vehicles. For loading into an ordinary wagon or cart, 24 cu. yd. per 10-hour day is about the upper limit for light material or material well loosened, 18 for material at the face of a cut which has been broken down onto a good surface for shoveling, and 15 for rather heavy plowed earth. At $1.50 per day these would give the following costs for labor, except foremen, of shoveling:

Light or well loosened material	6.25 cents per cu. yd.
Face broken onto good surface	8.25 cents per cu. yd.
Heavy plowed earth	10.00 cents per cu. yd.

In Engineering-Contracting, 1909, it is stated that experiments on a number of pieces of work involving the handling of thousands of yards of excavation have shown the long-handled shovel much superior to the short for handling earth. Men can do more work with less effort and can stand more nearly erect. It is stated that the long handle is used in Europe and the West, and the short handle in the East. The round-pointed shovel enters the earth easier than the square and is generally used except in shoveling from a platform when a square-pointed scoop should be used unless the material has to be cast a considerable distance.

Spreading and Dressing. A bankman will spread in 6-in. layers about 75 cu. yd. of average earth which has been dumped from carts or wagons; the cost therefore being about 2 cents a cubic yard with wages at $1.50 per day. For a railroad bank, it is usually only necessary to keep the surface smooth enough to drive over until grade is reached, in which case half a cent per cubic yard should be sufficient if the work is so planned that the bankman will be kept busy, *i.e.*, at least 300 cu. yd. must be delivered at the bank each day. If the earth is hauled in carts and dumped over the edge of the bank, about one-quarter of a cent per cubic yard should still be allowed for keeping the dumping place in order. Earth in large quantities can be spread by a team and road machine or Shuart grader for from one-half to three-quarters of a cent per cubic yard. In dressing railroad earth slopes from 125 to 150 sq. yd. per man per day is a fair average on construction work. This would make the cost about 1 cent per square yard. The cost per cubic yard would, of course, depend on the lightness of the work, the amount of material handled not being a proper criterion on account of the time spent in smoothing and skimming.

Superintendence, Timekeeping and Water Carrying. These items vary with local conditions, but half a cent per cubic yard will usually cover all three.

Wheelbarrows. The wheelbarrow is used for excavating small quantities of material and in cases where it is impracticable to use carts or scrapers on account of the cramped situation or deep mud in which horses could not work. It is also valuable for moving stony soil over short distances. Run planks or "gangways" should be provided and usually each man should load his own barrow. The load is about 1/14 cu. yd. for wheeling up slopes, as is generally necessary, but it may reach 1/10 for level ground. A study of the available data would indicate that the time for loading a cubic yard may be taken at 0.6 hour for the heavy soils and 0.5 for loam, while the time for wheeling, including dumping, adjusting the plank and other unavoidable delays, may be taken at 1/5 hour per cubic yard per 100 ft. for wheeling up slopes and 1/4 hour for level ground. Adding the cost of picking gives the following costs for labor except foremen, for picking and loading, with wages at 15 cents per hour:

Stiff clay or cemented gravel	19.0 cents per cu. yd.
Strong, heavy soil	16.5 cents per cu. yd.
Loam	12.5 cents per cu. yd.

to which should be added 3¾ to 5 cents for each 100 ft. of lead, depending upon the slope.

Drag Scrapers. The ordinary No. 2 drag scraper is a steel scoop weighing about 100 lb., which will hold from ¼ to ⅙ cu. yd., place measurement. It is drawn by a two-horse team which will travel at the rate of 2.5 miles per hour, or cover 100 ft. of haul per minute including loading and dumping, the haul making allowance for the extra distance required for turning at the pit and dump and being greater than the lead or straight line distance. An extra man is required to hold in loading while the driver usually dumps his own scraper. As a man can load for two or more teams, depending upon the lead, it is advisable to work the scrapers in gangs. The material should be well loosened so that the scoop will fill readily. J. W. Brown, Engineering Record, gives the following data based on the average cost of scraper work in Iowa. In making low embankments from side ditches with 6-ft. berms he makes the following assumptions: Distance, center of ditch to center of bank, 33 ft. Seven to ten trips per cubic yard. Sixty cubic yards per 10-hour day good average work. Plow team generally required to loosen the material, one plow to six scrapers. Two horses per plow required in light soil, four or more necessary in compact soil, average three at $6 per day with driver and man to hold. Field expenses, except management, and maintenance for loosening, loading and dumping, 360 cu. yd.:

Three-horse team with driver and plowman, loosening	$6.00
Three men holding scrapers, loading	4.50
One man dumping	1.75
One foreman	2.50
Maintenance, plows and scrapers	0.90
Total	$15.65

This gives 4.35 cents per cubic yard. The cost of hauling at $3.50 per day for team and driver is 5.83 cents, giving a total cost of 10.18 cents per cubic yard for the lead of 33 ft. For double the lead, or 66 ft., the yardage would be reduced to 40 per scraper per day, requiring 9 teams or $31.50 for hauling, while for a lead of 100 ft. the number of teams must be increased to 12 or the cost to $42. the other expenses remaining the same except that maintenance would be increased to $1.08 and $1.44, respectively, giving 8.75 cents and 11.66 cents for hauling and an increase of 0.05 cent and 0.15 cent for maintenance. For the above prices and material these data give the following rule for field expenses, except management, and maintenance for the drag scraper: To a fixed cost of 7.2 cents per cubic yard add 9 cents per 100 ft. of lead with 20 ft. as a minimum value to allow for turning. For stiff clay 25 to 30 per cent. should be added to the above.

Fresno Scrapers. The fresno scraper is an improved form of drag scraper invented in California and used mainly in the West.

The four-horse scoop is 5 ft. long laterally and only about 18 in. wide from cutting edge to rear, the former giving large capacity and the latter easy filling. Two- and three-horse sizes are also made. The horses are driven abreast by one driver. The four-horse scraper weighs from 275 to 310 lb. Many fresno loads at the dump have been compacted into a box with a rammer and found to run from 12 to 16 cu. ft. in average earth where the lead was not so great that much material was lost in transit. The editors of Engineering-Contracting give the following rules for estimating cost, based on a study of a large number of data: When the daily wage of a driver is $2 and that of each of the four horses is $1 a total of $6 per fresno per 10-hour day, the average cost, not including plowing, trimming or superintendence, will be as below: To a fixed cost of 4 cents per cubic yard add 2 cents per 100 ft. of lead. The fixed cost includes traveling the extra distance and the slower speed in loading, the shifting to newly plowed ground, etc. The hauling cost is based upon a traveling speed of 200 ft. per minute when not delayed by loading, dumping, etc., and upon an average load of ½ cu. yd., with 50 ft. as the minimum lead. If the soil is not of a kind that heaps up and drifts well in front of the scraper, the average load will probably not exceed ⅓ cu. yd. particularly on long hauls. This would change the rule to: To a fixed cost of 4 cents per cubic yard add 3 cents for each 100 ft. of lead. The editors believe that the horses can be crowded so as to do about the same amount of work in an 8-hour day as in a 10-hour day, or that the cost per cubic yard would be but slightly affected, but experience in the East with 8-hour days would hardly warrant this belief. They state that the cost of plowing ordinarily ranges from ¾ cent to 1.5 cents per cubic yard, foreman's wages, from ½ to 1 cent, and dressing roadbed and slopes about ¼ cent per square yard of surface trimmed. If the cost of plowing, dumping, maintenance and superintendence be added on the basis of $10.25 for 300 cu. yd. with ¼ cent per cubic yard for maintenance, as previously given, the fixed cost would be increased by 3.1 cents, giving: To a fixed cost of 7.1 cents per cubic yard add 2 cents per 100 ft. of lead, or to a fixed cost of 7.1 cents per cubic yard add 3 cents per 100 ft. of lead, according as the material heaps up and drifts in front of the scraper. This allows the driver $2 per day and requires him to load his own scraper, thus increasing the cost about ½ cent per cubic yard per 100 ft. of lead, and reducing it 1¼ cents independent of lead, as compared with the drag scraper figures previously given.

Wheel Scrapers. With the wheel scraper, the steel scoop is hung between two wheels with broad tires and it can be lowered and filled, raised or dumped, while the team is in motion. The capacity, place measurement, ranges from about 6½ cu. ft. for the No. 1 to 12½ for the No. 3, while the loads actually carried are about 0.2, 0.25, 0.4 cu. yd., respectively, for the three sizes. These loads can be increased for long leads by finishing with shovels when the material does not fill readily. The dead load varies from 350 to 800 lb. according to size. A snatch team is generally used loading all but the No. 1, even then shovelers are necessary if the box is to be filled in tough clay. In scraper, as in other work, the details must be carefully studied and given attention if economical results are to be secured. Thus the plow should be set to cut 10 to 12 in. deep, or to such a depth that the scoop will be heaping full after traveling but a few feet. The rear portion of the pan will not fill well with shallow plowing. The furrows should be close together, and if the soil is heavy it should be plowed twice. The bottom of the cut should be kept level so that the scoop will lie flat and not tilted. J. W. Brown, Engineering Record, as the result of experience in Iowa, gives the same costs, not including scraper teams and drivers, for handling 360 cu. yd. of earth with the No. 1 wheeler as were given for the drag scraper on page 11, except that the 90 cents for maintenance is increased to $1.40. He assumes four loads per cubic yard and about 100 ft. of lead per minute while traveling, or 60, 40 and 30 cu. yd. per scraper per day for leads of 100, 200 and 300 ft., respectively, requiring 6, 9 and 12 wheelers for transporting the 360 cu. yd. over the respective distances. He also increases maintenance slightly for the longer leads. These values would give for the No. 1 wheeler at $3.50 per 10-hour day, for average soil: To a fixed cost of 7½ cents add 3 cents for each 100 ft. of lead, with 75 ft. as a minimum. For leads over 300 ft. Mr. Brown uses No. 3 wheelers with two men to hold a scraper (requiring one extra holder) and a two-horse snatch team to aid in loading. To move the 360 cu. yd. per day he used eight wheelers for a lead of 400 ft., 10 for 500, 12 for 600, 14 for 700 and 16 for 800, the limit to which he considers it advisable to go with wheel scrapers. Adding $3.50 for the snatch team, $1.50 for the extra man to hold and $0.90 as lead increases for extra wear to the fixed cost, will give a total of $21.15 per day, or 5.88 cents per cubic yard for the fixed charge. Adding to this $3.50 per scraper for the different leads and dividing by 360, the number of cubic yards moved, will give the cost for hauling. The cost per cubic yard is given quite closely by the following: To a fixed cost of 5½ cents add 2 cents for each 100 ft. of lead within the limits of 300 and 800 ft. For a No. 2 the cost would be given approximately by the following: To a fixed cost of 6½ cents add 2½ cents for each of 100 ft. of lead within the limits of 200 to 500 ft. Good roads are essential to economy, especially with the No. 3 wheeler. These are for average conditions. For light material $4.50 per day could be saved for the No. 1 wheeler by having the drivers hold their own scrapers, while for heavy clay, a three- or four-horse snatch team with an extra man to hook and unhook would be needed for the No. 3, instead of the 2-horse team. Four horses might also be needed for the plow team. Scrapers are used to some extent for loading cars and wagons through a platform, over which the teams are driven and the material dumped through an opening.

Carts. The one-horse cart, although not used so much as formerly, is economical for short leads when shovel loading is employed and is convenient in turning and in dumping over the end of an embankment. Five is a suitable number of shovelers for loading, two on each side and one in the rear. They can load a cart with ⅓ cu. yd. in 2⅓ minutes, while about 1 minute is required for turning and dumping, making a total of, say, 4 minutes per trip, allowing for turning into place for loading. A driver can attend two carts, by dumping one while the other is being loaded, for leads up to 300 ft. For greater leads he can attend to two by taking them both together to the dump. At $1 per day for a horse and $1.50 for a driver this would give for 100 ft. of lead per minute and 3 trips per cubic yard:

⅞ cent per 100 ft. of lead, driver to 2 carts.
1¼ cents per 100 ft. of lead, driver to 1 cart.

For the fixed cost,

Four minutes per trip	3½	cents
Shoveling, average material	9	cents
Plowing	2	cents
Dump	½	cent
Foreman and maintenance	1	cent
Total per cubic yard	16	cents

This gives for field expenses, except management and maintenance:

To a fixed cost of 16 cents, add ⅞ cent for each 100 ft. of lead.

With one driver per cart, the 4 minutes will cost 5 cents giving:

To a fixed cost of 17½ cents, add 1¼ cents for each 100 ft. of lead.

This is on the supposition that the number of carts is so proportioned to that of the shovelers that both can be kept busy, otherwise the cost may be much greater.

Wagons. These may have an advantage over carts for long leads on account of the larger load, but they are at a disadvantage in turning. The slat-bottom box used for grading with an ordinary wagon is 3 by 9 by 1 ft. giving a capacity of 1 cu. yd. of loose earth, or about 0.8 cu. yd. place measurement. This is a full load for temporary roads over soft earth and up steep pitches, as in most railroad work. For long hauls over hard roads, as in road improvement and city work, additional side boards are much used, increasing the load to 1¼ to 1½ cu. yd., place measurement. The slat-bottom box has about 3 by 4-in. slats for the bottom and requires a man at the bank to aid the driver in dumping, which takes about 1½ minutes for the 0.8-cu. yd. or 3 minutes for the 1½-cu. yd. load. Dump wagons which can be dumped and the bottom closed again without stopping the team are rapidly coming into use. Enough men should be put in the pit to load a cubic yard in about 5 minutes. This would give at 35 cents per hour for team and driver, 3 cents for loading time, or about 4 cents total for loading and dumping time with slat-bottom wagons. If inconvenient to use so many shovelers an extra wagon may be loaded while the team is going to the dump so that by shifting the lost time can be kept about the same. If the earth is plowed and shoveled, with foreman and maintenance increased to 1½ cents this would give for field expenses, except management, and maintenance for a speed of 2.5 miles per hour, or 220 ft. per minute when traveling:

To a fixed cost of 17 cents, add ½ cent for each 100 ft. of lead, loads of 1 cu. yd., place measurement.

For different loads the amount to add for each 100 ft. of lead would be as follows:

Load of 0.8 cu. yd. add 0.66 cent per 100 ft.
Load of 1 cu. yd. add 0.53 cent per 100 ft.
Load of 1.5 cu. yd. add 0.35 cent per 100 ft.
Load of 2 cu. yd. add 0.26 cent per 100 ft.

Frequently wagons can be loaded with scrapers dumping through a platform cheaper than with shovels. The following data are taken from Engineering-Contracting, 1907, for the cost of excavating a street of a western city to a depth of about 2 ft., using a plow and drag scrapers. A 10 by 12-ft. platform was built with a floor of 2-in. plank on 6 by 6-in. stringers high enough to give a clearance of about 7.5 ft. An opening 2 ft. square was left in the center through which the material was dumped automatically by the front end of the scraper catching on a cleat nailed in front of the hole. This aided but did not do away with the dumpman. There were two inclined runways. The approach was steep and soon banked with earth; the run off was on a 15 per cent. gradient. The street gradient was 6 per cent. and the material was hauled down grade an average distance of 120 ft. in direct line. The platform had to be moved from time to time. The wagon loads averaged 2 cu. yd. in place and a wagon was filled by scraper loads in less than 6 minutes, or at the rate of more than 20 cu. yd. per hour. The labor cost, except foreman, of loading per hour was as follows:

One plow team	$0.40
One man holding plow	0.20
One man holding scraper	0.20
One man at dump	0.20
Five scraper teams	2.00
Total for 20 cu. yd	$3.00

or 15 cents per cubic yard. The No. 1 wheel scraper should give better results than the drag scraper for this lead.

Power Shovels. The standard machine for loading large quantities of material is the power shovel. It is usually operated by steam, but sometimes by electricity. It will handle earth, loose rock, and even cemented material without loosening. Solid rock must, of course, be blasted and it will often prove economical to loosen cemented material and loose rock. The ordinary shovel is usually mounted on standard gage trucks and provided with propelling chains. The boom swings through an angle somewhat over 180 deg. Jacks outside the tracks are used at the front corners to give a broader base for stability while at work. Some of the smaller shovels are balanced on a car and can swing through a full circle. Some of the makers mount these on traction wheels for highway and street work, cellar excavation, etc. Shovels with short booms are also made for tunnel and mining work. The dipper dumps through a door at the bottom and for light material its capacity is sometimes increased by providing an extension or lip in front. For hard material dippers are fitted with steel teeth. Heavy machines with smaller dippers than for earth are usual for hard digging and for handling large boulders. Steam shovels are usually operated by three men, the engine-man or runner, the cranesman and the fireman. The engineman controls the raising and lowering of the dipper and the swinging of the boom, while the cranesman regulates the depth of cut or "bite," releases the dipper from the bank when full and dumps the load. Pitmen, usually four to six, prepare for and move the short sections of track forward, operate the jacks and chocks in moving, etc. An excellent analysis of the cost of steam shovel work and discussion of the factors affecting the same are given in a Handbook of Steam Shovel Work published by the Bucyrus Company, South Milwaukee, Wis., it being a report by the Construction Service Company, based on records and time studies given in full for forty-five Bucyrus shovels working under different conditions as to material, depth of cutting, size of cars, number of cars in a train, management, etc. A formula is given for cost of loading cars, in cents per cubic yard, place measurement, for shovel work only, including plant expenses, and labor (except superintendence) and materials of field expenses, in which

d = time in minutes to load 1 cu. ft., place measurement
c = capacity of one car in cubic feet, place measurement
f = time shovel is interrupted to spot one car
e = time shovel is interrupted to change trains
g = time required to move shovel
L = distance of one move of shovel in feet
M = minutes per shift less loss for accidental delays
A = area of excavated section in square feet
R = cost per cubic yard on cars
n = number of cars per train
C = shovel expense in cents per shift

From these,

$$R = \frac{27C}{M}\left(d + \frac{f}{c} + \frac{e}{nc} + \frac{g}{LA}\right)$$

Using estimated values of C and A and the average values given below (or estimated ones) for the other terms except M and d, a plate of cost curves may be plotted for any value of LA showing the relation between R and d for various values of M. To estimate C, a $14,000 shovel is assumed, with the following data:

	Cost per year
Depreciation, 4⅔ per cent	$653.34
Interest, 6 per cent	840.00
Repairs, when working one shift	2000.00
	$3493.34
Per year of 150 working days, or $23.29 per working day	$23.29
Shovel runner	5.00
Cranesman	3.60
Fireman	2.40
One-half watchman at $50 per month	1.00
Six pitmen at $1.50	9.00
One team hauling coal, water, etc., half day, say	2.50
Two and a half tons coal at $3.50	8.75
Oil, waste, etc., say	1.50
Cost per day, C/100	$57.04

The depreciation is found by distributing the difference between first cost, assumed at $150 per ton, and scrap value, $10 per ton, over the life of the shovel, assumed as 20 years. It is stated that "The cost of repairs should be apportioned to the work turned out rather than considered as a function of the age of the shovel. It will be higher for rock than for earth-work and higher for badly broken rock than for well-blasted material." In assuming 150 working days per year, allowance has been made for bad weather, lack of continuous work, transportation of plant, etc. The actual number will be greatly affected by local conditions. The fuel consumption assumed for the heavy shovel used checks fairly well with some data given by Gillette, Handbook of Cost Data. His values for coal and water per 10-hour day vary from ¾ ton and 1500 gal. for a 35-ton shovel with a 1¼-cu. yd. dipper to 2¼ tons and 4500 gal. for a 90-ton shovel with a 3-cu. yd. dipper. The average shovel move, *L*, was 6 ft. *A* varies with the depth and width of cut. For example, values of 250, 500 and 1000 sq. ft. are used in the Handbook in computing cost curves. The larger the volume, *LA*, per shovel move the less the cost per cubic yard. The width of cut and *L* are fixed by the reach of the shovel. In increasing the depth to increase *A*, the danger of landslides should be considered as also the height of the loading track if cars are handled in trains alongside the shovel. On the other hand, if the depth reaches a certain minimum, varying with the material, such that the dipper will not fill in one raise, the cost will also be increased by increasing *d*, the time required to load a cubic foot. The time *d*, required to load 1 cu. ft. depends upon the material, the depth of cutting, the shovel and the capacity of its dipper, as well as upon the skill and cooperation of the engineman and cranesman. These men must work together perfectly or costs will be seriously affected. The results of the tests taken show that the average time to load 1 cu. yd., place measurement, is about 10½ seconds for iron ore, 12 for sand, 18½ for clay and earth and 31½ for rock. These were with average dipper capacities, place measurement of 1 cu. yd. for rock, 1¼ for earth and sand, 1½ for clay and 2½ for iron ore. The average ratios of place measurement to water measurement for the dippers were 0.94 for iron ore, 0.56 for sand, 0.61 for clay, 0.53 for earth and 0.43 for rock. The time, *f*, for spotting cars is usually zero, as it is done while the shovel is turning and digging. This is where the train is alongside and moved a car length at a time without switching. The capacity, *c*, is taken as 4 cu. yd., water measurement, or 2.5, place measurement, for ordinary contracting work where 10 car trains of side dumping cars are most common, or *n* = 10. The time, *e*, the shovel was interrupted to change trains averaged 4 minutes. The average time, *g*, required to move the shovel averaged 8 minutes. It depends upon the skill and cooperation of the crew and pitmen, and should be done according to a definite schedule. The time lost by accidental delays, to be subtracted in finding *M*, averaged about 7¼ per cent. for brick clay, 8½ for sand, gravel and iron ore, 17½ for earth, clay and loam from railroad borrow pits and crushed stone from quarries, and 20 for rock cuts on railroad work; with a maximum of about 40 per cent. for borrow pits of earth and 56 for rock cuts. These delays may be due to the condition of the material or to breakdowns or to accidents. Thus, wet clay often clogs the dipper teeth and sticks in the bucket. Delays are most frequent, however, in handling rock, especially if it has not been properly broken. Large pieces have to be "chained out" or broken by mud capping or block-holing and blasting, thus seriously delaying the shovel. Small air hammer drills can be used to advantage in block-holing as the hole can often be drilled on the side of the stone away from the shovel and the stone broken by light charges. Every effort should be made, however, to properly break the rock with the original blasts. Holes a few inches too shallow or with the bottoms not properly loaded often leave ridges which must be drilled and blasted before the track for the shovel can be laid. Delays due to breakdowns should be minimized by keeping duplicate parts liable to breakage on the job and training the men to make repairs quickly. The shovel should be carefully inspected each night and parts liable to break the next day replaced. It should be noted that the use of average values of the various factors will give only what may be considered standard cost curves. But estimated values, or actual ones from time studies, are easily used, thus making it possible to vary conditions and determine what plan of operations gives the best results. The Bucyrus formula shows clearly that delays, either e, f and g, or those which reduce the value of M, increase R, the cost of loading, and they may also increase the cost of transportation. The best efforts of the management should therefore be directed toward reducing these, both by the use of proper general design and plan of operation, and by careful supervision during the progress of the work.

Steam Shovels for Light Work. For light work or for loading into wagons or small cars a small shovel is often preferable. It is estimated, for example, that the Thew 13-ton full swing shovel with traction wheels and ⅝-cu. yd. dipper can be operated for $13.50 per 10-hour day, as follows:

Engineman	$5.00
Fireman	2.00
Two pitmen	3.00
Fuel at $4 per ton	2.00
Supplies and repairs	1.50
Total	$13.50

It is claimed that it will excavate some 35 cu. yd. per hour in ordinary soil, while if the engineman does his own firing and but one pitman is used the cost can be reduced to about $7 and the capacity will be about 25 cu. yd. per hour. Allowing 1 minute delay per load in getting the 1-cu. yd. wagons into place and a little extra time for moving, this would give 20 cu. yd. per hour, or 200 per day for the full crew. Dividing $13.50 by 200 would give 6¾ cents per cubic yard for loosening and loading. This does not include delays, depreciation or interest.

Electric Shovels. When electric power is available, a considerable saving can be made by the use of the electric shovel, in which electric motors displace the steam engines and boiler of the steam shovel. In the construction of the Brantford and Hamilton (Ont.) Electric Railway, an electric shovel of 1 to 1½ cu. yd. capacity was used. When this shovel worked in the gravel pit the depth of the cut was about 14 ft. The gravel was loaded onto flat cars having 14-cu. yd. capacity each, and frequently 100 loaded cars were hauled away daily. This meant an output of 1400 cu. yd. loose measurement, or 1050 cu. yd. placed measurement. The labor cost for a day was $29.50, divided as follows: One superintendent, $4; shovel crew, consisting of two shovel men at $3 and two pit men at $1.50; one motorman at $3 and one signal man at $1.50 for spotting cars; transporting two trains, requiring two motormen at $3 each and two trainmen at $1.50 each; and two men at the dump at $1.50 each. With 1050 cu. yd. removed in a 10-hour day, the labor costs were as follows: Superintendence, $0.004; loading, $0.013; transportation, $0.009; dumping, $0.003; total, $0.029 per cu. yd. When the output fell to 800 cu. yd. place measurement, the total unit labor cost was $0.037 per cubic yard. This extreme minimum figure, of course, does not include charges for power, plant, repairs and track work.

The Chautauqua (N. Y.) Traction Company gives the cost of power and labor for a 1½-cu. yd. electric shovel, working in a mixture of gravel, sticky clay and sand as:

1 man (daily)	$2.67
1 man	2.00
2 men @ $1.20	2.40
163 kw.-hr. at $0.0088	1.43
Oil and waste, etc.	0.30
	$8.80

534 cu. yd. were handled per day, making the cost about 1.64 cents per cubic yard. This with shovel idle about one-half the time.

Mr. W. C. Sparks, of the Rockford (Ill.) & Interurban Railway gives the following data on the cost of loading and hauling gravel for 1 month, with the following equipment: Shovel, Thew electric No. 1, full circle swing dipper 1¼ yd. Three work train motor cars, each with four GE-57 50-HP motors; ballast cars, thirteen 12-yd. Western center dump. Conditions: 15-ft. bank of gravel; 4 per cent. grade out of pit; average daily mileage of work trains, 120; shovel operated by three men; foreman's time divided between pit and surfacing gang; shovel not operated to capacity because of inability to keep cars spotted for loading; power conditions only fair; work trains cleared regular trains; no charge made for repairs to work and ballast cars; total yardage for month, 6630. The detail of the cost was as follows:

Miscellaneous

Shifting track—12 men 3 hours at 0.20	7.20		
13 men 3 hours at 0.20	7.80	15.00	
Oil and waste for shovel	1.60	1.60	
Repairs—1 man 12 hours at 0.25	3.00		
1 man 8 hours at 0.25	2.00		
Material	1.25	6.25	22.85–0.0034 per yard

LOADING

Foreman 31 days at 1.25	38.75		
Operator 324 hours at 0.25	81.00		
Labor 540 hours at 0.20	108.00	227.75	
Power used by shovel 0.00167 per yard estimated	10.97	10.97	238.72—0.0360 per yard

TRANSPORTATION

Work train crews 1129 hours at 0.25	282.25	282.25	282.25—0.0420 per yard

STRIPPING

36,500 yd. gravel	1825.00	1825.00	1825.00—0.0500 per yard

POWER

1680 miles loaded at 0.08	134.00		
1680 miles light at 0.06	100.80	235.20	235.20—0.0355 per yard
Average cost for month			0.1669 per yard

Mr. Sparks also gives cost of loading and hauling dirt for a bridge fill during October, 1913, as follows: Equipment: Shovel, Thew Electric No. 1, full circle swing dipper 1¼ yd.; one work train motor car with four GE-57 50-HP motors, and three 12-yd. Western side dump cars. Conditions: Twelve-foot bank of dirt—hardpan in bottom; no grade out of cut; average daily mileage of work train, 50; shovel operated by two and three men; no superintendence charged; power conditions good; work trains cleared regular trains; no charge made for repairs to work on dump cars; total yardage for month, 9240. The detail of cost was·

MISCELLANEOUS

Repairs—1 man 14 hours at 0.25	3.50		
1 man 7 hours at 0.25	1.75		
Material	3.75	9.00	
Oil and waste	1.50	1.50	
Installing siding—			
Foreman 2 days at 2.50	5.00		
Labor 200 hours at 0.20	40.00	45.00	
Shifting track—			
Foreman 2 days at 2.50	5.00		
Labor 185 hours at 0.20	37.00	42.00	
Removing siding—			
Foreman 1 day at 2.50	2.50		
Labor 47½ hours at 0.20	9.50	12.00	
Installing overhead, phone, etc.	15.00	15.00	124.50—0.0134 per yard

LOADING

Operator 369 hours at 0.25	92.25		
Labor 431 hours at 0.20	86.20	178.45	
Power used by shovel 0.00167 per yard estimated	15.44	15.44	193.89—0.0209 per yard

TRANSPORTATION

Work train crews 704 hours at 0.25	176.10	176.10	176.10—0.0190 per yard

LABOR ON FILL

Foreman 2 days at 2.50	5.00		
Labor 345 hours at 0.20	68.00	73.00	73.00—0.0079 per yard

POWER

775 miles loaded at 0.08	62.00		
775 miles light at 0.06	42.50	108.50	108.50—0.0117 per yard
Average cost			0.0729 per yard

The Milwaukee Electric Railway & Light Co. gives as follows the records of operation of an electric shovel while excavating track trench in city streets, lifting the loose gravel and crushed stone material into 5-yd. dump cars on the adjacent tract. The operating costs of this shovel on eight jobs approximating 24,060 cu. yd. was $3,584.25, or approximately 14.9 cents per cubic yard. This includes labor, power, oil, etc. To the above cost should be added the fixed charges on the investment of $4000, as follows:

Interest, taxes, etc	8 per cent.
Depreciation	12 per cent.
Maintenance	5 per cent.
Total annual charge	25 per cent. or $1000

being approximately 4 cents per cubic yard, making a total of 18.9 cents per yard as the cost of owning and operating this shovel for a season's output of 25,000 yd. Part of this work was done entirely on construction work, namely, new tracks, but that part done on the operating tracks excavation was done at night, mainly during the time of the owl car operation. In some cases, however, at the outer ends of the lines stub service was operated during the early hours of the night. It was not found necessary to provide a temporary running track.

The Indianapolis Traction & Terminal Co. states that it uses its shovel to excavate, grade and sub-grade, in city streets. The ditch is 9 ft. wide by 24 in. deep, and an average day's work is 340 lin. ft., maximum 410 lin. ft. Work less than 300 ft. is due to obstructions, gas, water pipes, conduits, manholes, etc., requiring to back up the shovel to get over them. The shovel crew consists of:

1 operator at 0.30 per hr	$3.00
1 foreman at 0.25 per hr	2.50
8 laborers at 0.17½ per hr	14.00
226 cu. yd. at 8 6/10 cents equals	$19.50

To do an average day's work requires a move every 6 or 7 minutes, each move being 4 ft. With deeper digging and less frequent moves a greater number of cubic yards can be handled. It makes no material difference as to the character of the excavation, that is, clay, gravel, old paving concrete and old ties. The old rail is pulled out with a crane car and then the shovel is put in after removing any of the old paving that has value. No current charge is made, but it will average about 35 amperes on 550 volts. On clay digging in 4-ft. bank the machine averaged 420 lin. ft. ditch 9 ft. wide, with same crew. In all cases material was loaded into 6-yd. standard gage Western dump cars.

Hauling with Cars and Dinkey Locomotives. On new construction this is the standard method of hauling material excavated with steam shovel. The usual gage is 3 ft. The cars are side dump of 3 or 4 cu. yd. capacity the latter weighing about 6000 lb. The dinkey weighs from 8 to about 30 tons; all on drivers. This light weight allows the use of rails of from 16 to 40 lb. per yard. With 5-ft. ties about 6 by 6 in. in section, it makes a light track which can be easily shifted at cut or dump as required. The following rental rates were quoted by an equipment company, July, 1911.

Four-cu. yd. 3-ft. gage Western cars,	
First month	$10.50
Second month	10.20
Third to fifth month inclusive	9.60
Sixth to eighth month inclusive	9.00
Each month thereafter	8.40

Twelve-ton dinkey,	
First month	$141.00
Second month	132.00
Third to fifth month inclusive	117.00
Sixth to eighth month inclusive	101.00
Each month thereafter	93.00

The rolling friction on this light track is from 20 to 30 lb. per ton and probably more in starting on dirty track. The dinkey can exert a pulling force of about one-fourth of its weight. The speed is about 5 miles per hour when loaded and 8 to 9 when empty or on down gradients with smooth track. One dinkey is often used with a 1½-cu. yd. shovel for leads up to 1000 ft. With six cars and three or four dumpmen the train can be dumped in about 2 minutes so that good results can be obtained. For longer leads, a second engine would be required for spotting cars, with cars enough for two trains, one dumping while the other is loading. The length of train and weight of engine should increase with the lead when the work is heavy enough to warrant it.

Hauling with Cars and Horses. Two-foot gage 1-cu. yd. capacity cars weigh about 1000 lb. each and 1½-cu. yd. cars about 1350, so that one horse can draw three loaded cars if favored slightly by the gradient for the heavier cars. Fifteen to 20-lb. rails are heavy enough, with plank or round timber ties. A side track is put in at the cut and two trains are used the same as for dinkey engines. For hand loading both tracks should extend into the cut and be used alternately to save work in switching. Allowing the driver 6 minutes for dumping and 1 minute at the cut, the fixed cost, at $1.50 for the driver and $1.00 for the horse, would be 1 cent per cubic yard for the heavier cars, 1 cu. yd. place measurement, while the cost per 100 ft. of lead would be 0.14 cent, giving for the cost of hauling per cubic yard: To a fixed cost of 1 cent add 0.14 cent for each 100 ft. of lead. For level or slightly rising track, requiring the 0.8-cu. yd., place measurement, cars, this would become: To a fixed cost of 1¼ cents, add 0.18 cent for each 100 ft. of lead. This assumes a dumping trestle and no trackwork or depreciation. The trackwork would cost much less than for the shovel and dinkey, especially at the cut. One cent plus 0.2 cent per 100 ft. of lead should cover ordinary conditions. With no dumping trestle 1½ cents per cubic yard should be added for spreading and about 1 cent for extra shifting of track. This would give for the cost of transportation: To a fixed cost of 4.5 cents add 0.34 cent for each 100 ft. of lead, or to a fixed cost of 4¾ cents add 0.4 cent for each 100 ft. of lead, according as 3 or 2.4 cu. yd. are hauled per train. To this must be added the cost of loosening and loading.

Power Shovel and Standard Equipment. Standard gage flat cars and ballast cars are used on maintenance work in widening cuts and fills, filling old trestles, reducing gradients, distributing ballast, etc. The flat cars are unloaded by a plow drawn by cable. The ballast or dump cars are dumped through doors operated by air from the brake system. For the heavy cars, inclined floors rather than tilting bodies make them self cleaning. The capacities of the flat and ballast cars range from 10 to about 30 cu. yd. The cost of loading with power shovel and hauling on good track with large cars is less than with the small cars and poor track used on new work, provided the forces can be so adjusted as to keep all busy. Usually, however, the work must be done subject to interruption from traffic so that a careful study of conditions must be made in order to estimate costs. W. Beahan, First Asst. Engr., L. S. & M. S. Ry., in a letter dated October, 1911, places the cost of grading for third and fourth track, using standard equipment and a haul not exceeding 5 miles including loading, unloading and leveling ready to lay the ties, about as follows per cubic yard:

Borrow pits or cuts with 15-ft. face	$0.11
Earth cuts, 3 to 10 ft. deep	0.15
Shale cuts, all blasted	0.21
Other rock cuts all blasted and requiring breaking up by blockholing	0.25

This includes labor and supplies as follows:

Foreman per month	$75.00
Laborers per hour, 10-hour days	0.15
Steam shovel crew, 8 men per 10-hour day	25.00
Train service, labor and supplies per day	28.00

Interest, depreciation, explosives and overhead charges are not included. The repairs for shovel probably are included as the labor was performed by the shovel crew. Mr. Beahan states that in moving a short distance where overhead obstructions will allow, they sometimes let the dipper rest on a flat car, remove the jack arms and haul the shovel with the work train; but that usually it is best to take the shovel down even for moving a short distance, and they estimate that it will cost $100 to take a shovel out of one cut and put it in another, although they can occasionally do it for $50. A. J. Himes, Engr. of Grade Elim., N. Y. C. & St. L. R. R. Co., gives the cost of moving a shovel about 3½ miles through the City of Cleveland in August, 1911, as follows:

Labor:		
Taking down		$23.26
Moving		49.11
Setting up		23.27
		$95.64
Work Train Service:		
Placing cars to load parts and helping to take down	$10.20	
Moving shovel and bunk cars	8.50	18.70
		$114.34

The cost of shipping the above shovel from Ashtabula to Cleveland and setting up is given as follows:

Freight: shovel and three cars at $19.50	$78.00
Boarding car and tool car at $22.50	45.00
Lost time shovel crew	8.84
Setting up shovel	31.47
	$163.31

On new work, the cost of moving from the railroad to the site would be in addition to that of setting up, or taking down and setting up, as above. This may be over highways or across country. A track is required with force sufficient to take up and move forward ahead of the shovel. The shovel can be moved with its own power if the gradients are not too steep. If too steep for adhesion, one end of a rope can be anchored ahead, the other end wound around the driving axle and the running gear started. No general estimate of cost of moving can be given on account of the variation in conditions. The Bucyrus Handbook of Steam Shovel Work states that a 70-ton shovel was moved 1600 ft. in 8 hours by the shovel crew, 16 men, foreman and one team at a total cost of $34 or 2.12 cents per foot.

Culvert Openings. The following run-off formulas for culvert openings are taken from the report of Committee on Drainage of the Illinois Society of Engineers and Surveyors, 1913. In these formulas, M = area of watershed in square miles; A = area of watershed in acres; Q = maximum discharge entire watershed in cubic feet per second; q = maximum discharge per square mile in cubic feet per second; c = coefficient; a = area of opening required in square feet:

TALBOTT: $a = c\sqrt[4]{A^3}$. $c = 0.6$ for flatl and; $c = 0.85$ for moderate slope; $c = 1.1$ for steep slope

MYERS: $a = c\sqrt{A}$. $c = 1$ for flat land; $c = 1.6$ for hilly land; $c = 4$ for mountains

PECK: $a = \frac{A}{c}$. $c = 4$ to 6 (Missouri Pacific Ry.)

WENTWORTH: $a = A^{2/3}$. Applicable to conditions on Norfolk & Western R. R.

C. B. & Q.: $Q = \frac{3000M}{3 + 2\sqrt{M}}$

Cooley: (1) $Q = 200M^{5/6}$, (2) $Q = 180M^{5/6}$

Tidewater Ry. Co.: $a = 0.62A^{7/10}$

El Paso & Southwestern Ry.: $Q = 12\sqrt{\frac{8000}{M}}$

O'Connell: $Q = \dfrac{1421M}{0.311\sqrt{M}}$

Kuichling: For occasional floods: $q = \dfrac{44,000}{M + 170} + 20$;

for rare floods: $q = \dfrac{127,000}{M + 370} + 7.4$

Murphy: $q = \dfrac{46,790}{M + 320} + 15$

Gray: $q = 5.89M^{5/6}$

Fanning: $Q = cM^{5/6}$. $c = 130$ to 200 for New England and Appalachian watersheds; $c = 60$ to 100 for eastern middle states watersheds; $c = 12$ to 50 for western tributaries of Mississippi River north of Missouri River.

Wooden Trestles. The reasons for the common use of wooden trestles on new work are summarized in an editorial in the Engineering News as follows:

1. A well-built timber trestle, while it lasts, is a very solid and safe structure, and it lasts normally in good condition for from 5 to 10 years while much hastily built masonry gives out in 1 or 2 years.

2. There is more time to determine accurately the size of opening needed and thus avoid needless washouts; besides, well-built timber structures are less likely to wash out suddenly.

3. The time of construction is shortened materially, often an important consideration.

4. The masonry, when at last built, is almost certain to be better built and of better stone. Haul then is of less importance and there will be more time to secure good materials. The roads are few on which any large proportion of the original masonry is in good condition after 10 years. This is especially true of the smaller structures, such as cattle guards and open culverts which are often so poor as to shake to pieces in a few months. The lesson that the smaller the structure, the larger and better dressed must be the stones composing it, if it is to be durable, is one which engineers are slow to learn.

5. It is easier to introduce long and high fills afterward to be filled by train, or replaced by masonry or iron, and thus to secure a better alinement and avoid rock cutting or other objectionable work.

6. A very large part of the total cost of the line in its permanent form is postponed for 6 to 8 years past the trying years of early operation; thus not only saving the interest on the cost of the permanent work but going far to protect the company from the danger of early insolvency, which has proved so deadly to many overconfident companies.

7. The only necessary disadvantages are the liability to decay and fire. To guard against the former is a mere question of inspection. The danger from fire is a real one and every year has its record of accidents resulting therefrom, but if the danger is real it is small. There are few such accidents and those mostly from gross carelessness. In proportion to their number, accidents from iron structures have been vastly more numerous and more fatal, and the same is true in substance of small masonry structures where the great liability to washouts is a serious matter.

The reasons given above will apply to-day in sections where timber is cheap, the country and traffic undeveloped, and the company with scarcely sufficient means to put the road in operation. In improvements in alinement and gradients, or in building extensions and branch lines in a fairly well-developed country by a prosperous, well-established company, the conditions are different and the tendency is toward masonry structures with solid floors so as to give a continuous ballasted roadbed. In improvements under heavy traffic, as in track elevation or depression, grade reduction, etc., timber trestles are usually necessary to carry the track until the permanent roadbed is completed.

Quantities of Material and Cost of Wooden Trestles. The editors of Engineering-Contracting from a carefully prepared and tabulated bill of materials for the Northern Pacific Railway standard wooden trestle deduced the following formulas for preliminary estimates:

$$\begin{aligned} M &= 220 + 6H \text{ for } H \text{ between 20 and 25} \\ &= 240 + 8H \text{ for } H \text{ between 25 and 50} \\ &= 240 + 9H \text{ for } H \text{ between 50 and 75} \\ &= 240 + 10H \text{ for } H \text{ between 75 and 125} \end{aligned}$$

where M = feet B.M. in trestle, including deck, per lineal foot.
H = average height from ground to a point 3½ ft. below base of rail.

The division into groups is due to the construction of high trestles in stories, each story being about 25 ft. The bents are 15 ft. 9 in. centers. Each has four 12 by 12-in. posts, the outside posts having a batter of 3 in. per foot and the inside posts a batter of 1 in. per foot. The deck consists of six 9 by 18-in. stringers, with 8 by 8-in. cross ties 13½-in. centers and 5 by 8-in. guard rails, a total of 164 ft. B.M. per lineal foot of trestle. For the deck there are 40 lb. of wrought iron, 25 lb. of cast iron, and 25 lb. of galvanized iron, a total of 90 lb. per 1000 ft. B.M. of timber, or 15 lb. per lineal foot of trestle. For the bents and braces there are about 35 lb. of wrought iron and a little less than 15 lb. of cast iron per 1000 ft. B.M., a total of 50 lb. per 1000 or 0.05 lb. per foot B.M. of timber. This would give in pounds:

$$\text{Iron per foot of trestle} = 15 + 0.05\,(M\text{-}164).$$

If piles are used under the sills as for the Sante Fe, five would be required for the heights up to 25 ft. and six above that height. The average penetration will be from 12 to 18 ft., depending on the soil, requiring about 20-ft. piles.

For a pile trestle, four piles per bent, bents 16-ft. centers, with 20 ft. per pile allowed for penetration and cut off, lineal feet of piles per foot of trestle = $(20 + H)/4$, where H is the average height in feet to a point 3½ ft. below base of rail.

The sawed lumber per foot of trestle = 185 ft. B.M. for trestles under 15 ft. high.
= 200 ft. B.M. for trestles 15 to 25 ft. high.

The iron weighs 16 lb. per foot of trestle; 40 per cent. is wrought, 30 cast and 30 galvanized.

With bridge carpenters at $2.50 per day it is stated that the cost for framing and erection, including the handling of the iron, should rarely exceed $10 per 1000 ft. B.M., while the cost of driving the piles is placed at 7 cents per lineal foot of pile (not per lineal foot of penetration). Freight or freight and cartage must be added to the cost of the material if delivery was not included in the purchase price.

Steel Trestles. The general type of construction is with spans alternately about 30 and 60 ft. without much regard to height of trestle; longitudinal bracing is placed under the 30-ft. spans joining the vertical bents in pairs forming towers capable of resisting the longitudinal forces due to starting and stopping trains on the track. The open deck is carried by plate girders spaced to support the ties on the upper flanges; the bents are in vertical planes and the posts batter about 2 in. per foot. Each post rests on a masonry pier some 4 to 5 ft. square at the top and large enough at the base to reduce the unit pressure on the foundation to a safe value. Anchor bolts are set to templet before the pier is built and masonry thus adds to stability in the case of wind pressure strong enough to produce tension in the post.

The following formulas have been given for weight per foot of steel in terms of height of trestle:

1. C. P. Howard, Eng. News, 1906, for Cooper's E 40 loading.

Weight per foot = 520 lb. for height of 20 ft.,
= 1200 lb. for height of 60 ft.,
= 1530 lb. for height of 90 ft.

2. The above values with 20 per cent. added for Cooper's E 50 loading.

3. Editors, Eng.-Cont., 1907, for two 116-ton engines followed by 3000 lb. per foot, spans 30 and 60 ft. alternating.
Weight per foot = 600 + 12 times height.
It is claimed that this has been used in estimating the weight of many viaducts of different heights and has been found to give very close results except for heights as low as 20 to 25 ft.

4. H. G. Tyrell, Eng. News, 1900, for two engines weighing 100 tons each followed by 4000 lb. per foot. Unit stresses 10,000 and 12,000 lb. per square inch.

Weight per foot:
Deck plate girder = 100 + 9 times span,
= 550 for spans of 30 and 60 ft.
Bents and bracing = 9 times height.

5. Electric railway trestles for 25-ton cars, or 2000 lb. per lineal foot.

Weight per foot:
Deck plate girder = 30 + 5 times span,
= 260 for spans of 30 and 60 ft.
Bents and bracing = 6 times height.

Ballast. Broken stone ballast is usually given first place on account of its durability and stability. It drains well and is but slightly affected by weather conditions unless filled with snow and ice. It is expensive as it is difficult to get even support for the ties in working to line and surface, and a small lift in track cannot be made without breaking up the bed under the ties. The stone is broken to pass about a 2½-in. ring and the fine material up to about ½ in. should be screened out. By using two sizes, the large for the bottom and the small for the top, around the ties good drainage may be secured and the disadvantages in surfacing largely reduced. Granite, trap, many of the limestones and occasionally a sandstone will break into pieces which are fairly cubical and make durable ballast. Stone which breaks into flat or angular pieces is not satisfactory. Stone ballast should be handled with forks rather than with shovels to avoid dirt which interferes with drainage and encourages the growth of weeds besides being dusty. The cost varies greatly in different parts of the country, from 45 to 75 cents per cubic yard, f.o.b., at the crusher, being a fair average. The labor of placing under track and tamping will be from 15 to 25 cents per cubic yard. The cost of hauling by train and dumping from ballast cars will depend upon distance, density of traffic, etc.

Gravel is the material in most general use on account of its wide distribution and its many good qualities. The feeling is quite general among railroad engineers that for ordinary traffic track it will keep in better line and surface than broken stone. As a mass it is more elastic, easier on ties and rolling stock and less noisy, while track can be maintained in first-class condition at less cost. The size that will pass through about a 1½-in. mesh is considered best, although a larger size will give good results if combined with smaller stone and coarse sand. Fine sand or clay will retard drainage and encourage the growth of weeds; washing is sometimes resorted to with good results. Camp, in "Notes on Track," places the limits of cost commonly met with at 15 to 40 cents per cubic yard in place in completed track, 10 to 15 cents of which is due to handling the gravel after it is delivered on or at the side of the track. This includes the labor of placing it under the track, shovel tamping, filling in and dressing off.

Slag and burnt clay are used as substitutes for broken stone, the former when available at blast furnaces on account of lower cost and the latter in sections where broken stone can only be obtained by a long haul. The slag is preferred when poured so that it will spread out in thin layers. In this way it becomes hard and brittle and will break easily. It should contain but little free lime. In track it has about the same characteristics as broken stone and it

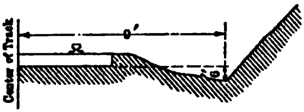


FIG. 2.—Ditch in dry gravel cut.

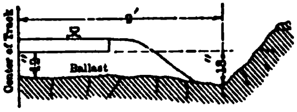


FIG. 3.—Ditch in shallow rock cut, ballast 12" deep.

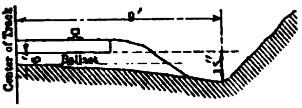


FIG. 4.—Ditch in dry earth cut, ballast 6' deep.

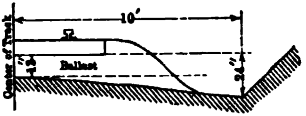


FIG. 5.—Ditch in wet earth or gravel, 12" stone or gravel ballast.

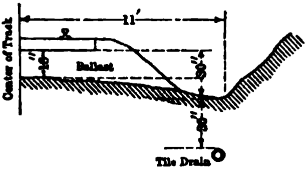


FIG. 6.—Ditch for springy roadbed, stone ballast.

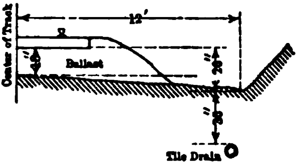


FIG. 7.—Ditch in clay cut, stone, or cinder ballast.

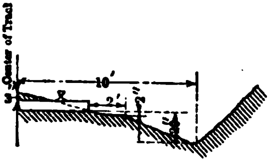


FIG. 8.—Ditch in cut, dirt ballasted track.

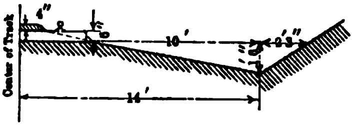


FIG. 9.—Section of earth in cut.

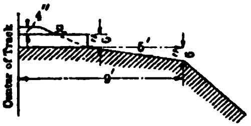


FIG. 10.—Section of earth on embankment.

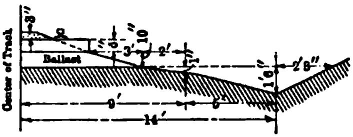


FIG. 11.—Section of cemening,t gravel ballast in cut.

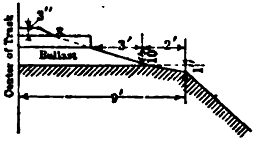


FIG. 12.—Section of cementing gravel ballast on embankment.

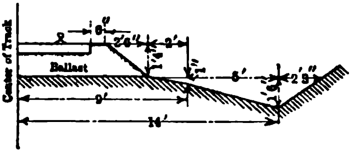


FIG. 13.—Section of coarse and loose gravel ballast in cut.

is used in the same manner. The burnt clay is obtained by burning gumbo or other suitable clay free from sand with coal slack.

The depth of rock ballast required to produce uniform pressure on the subgrade with ties 7 by 9 in. by 8½ ft. spaced 2-ft. centers is about 24 in. as determined by experiments on the Pennsylvania Railroad, Proc. Am. Ry. Eng. Assn., 1912, and by Director Schubert. The former experiments also showed that the lower 14 to 18 in. could be replaced with cinders without appreciably affecting the results.

Typical Earthwork and Ballast Sections, as given by Camp in "Notes on Track," are shown by Figs. 2 to 16, inclusive.

Ties. The timber cross tie should be 8 ft. long with a tendency to increase to 8 ft. 6 in. for heavy traffic. The usual thickness is from 6 to 7 in., 6½ to 7 in. would be better, while the minimum face should be about 6 in. for pole ties and 8 in. for those with rectangular section. The thickness should be uniform so that ties can be renewed without disturbing the old beds; differences in width can be provided for by varying the spacing to keep the bearing area per foot of track constant up to the limit for narrow ties which would interfere with tamping.

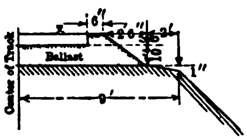


FIG. 14.—Section of coarse and loose gravel ballast on embankment.

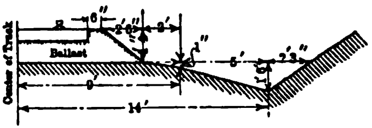


FIG. 15.—Section of stone ballast in cut.

White oak is placed at the head of the list of timber available in this country for durability from decay, holding spikes and freedom from rail cutting. Its life is from 5 to 10 years depending upon traffic and climate and to some extent upon ballast. Burr or rock oak, chestnut oak, and red oak are placed in order of value, the life of the last not being more than one-half that of white oak. Pine is next in importance on account of its abundance. The long leaf yellow pine will last nearly as long as the white oak, the loblolly rather more than one-half as long and the southern pitch pine about a mean of the other two. There are many of the other woods in use some of which as chestnut and cedar are durable but require tie plates for protection to secure full life, while others as hemlock, elm, etc., will decay in a few years unless treated. All ties should be stripped of bark and allowed to season thoroughly before being put in track.

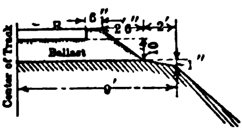


FIG. 16.—Section of stone ballast on embankment.

Wood Preservation. See index.

Effect of Zinc Treatment on Spikes. The Third Annual, Report of the Board of Supervising Engineers, Chicago Traction, states that examination of track built in previous years showed that where screw spikes had been inserted in ties treated with zinc chloride a deterioration of the spike resulted. The reason for the damage is believed to be local chemical and galvanic action in the bored spike hole, which usually contains water, each spike hole forming a single cell containing a strong solution of zinc chloride in which the screw spike is immersed. Free chlorine and hydrochloric acid gases assist in the destruction. While there seems to be no immediate remedy at hand which might be applied to stop or partially suspend the deterioration which is going on apparently at all times, the obviation of this difficulty in the future will be obtained by abandonment of zinc-treated ties for ties treated with creosote. Therefore, specifications have been revised to include only No. 1 white oak, 90 per cent. heart yellow pine (both untreated) and soft wood ties treated with creosoting process only.

Cattle Guards. A wooden slat guard used on the Illinois Central Railroad is shown in Fig. 17. It is made of 2 × 4-in. oak slats, put together in four sections, each held by three ⅝-in. bolts. Each section is held down at the end with a piece 2 by 6 in. beveled to correspond with the bevel at the end of the slats; that at one end is spiked and that at the other held by lag screws for convenience in removal for repairs or track work. The ballast should be partially removed between the ties, so that the slats will not have the appearance of a solid support. Camp advocates a length of at least 15 ft. as being more effective in turning ranch stock than the length of 9 to 10 ft. in common use. Whitewashing the guard and the guard fences so as to give opportunity for stock to turn aside rather than to walk into a pocket will increase the effectiveness of the guard. Metal guards of various patterns are also in use. The cost of wooden guards ready for use is from $15 to about $30, de-

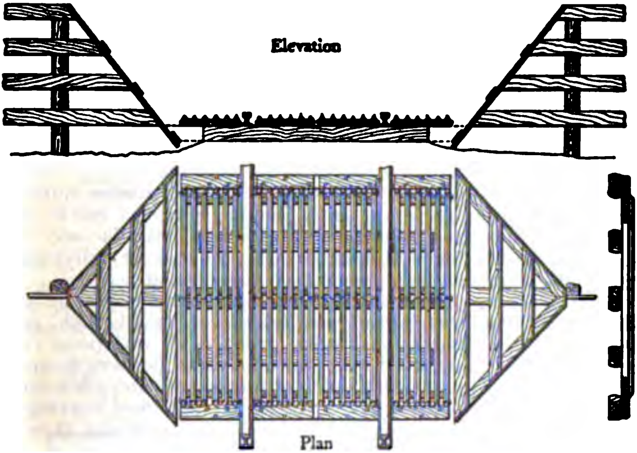


FIG. 17.—Wooden surface cattle guard.

pending upon length and size of slats. The cost of metal guards of sufficient strength to be durable would be somewhat greater. To this must be added cost of placing and the cost of the fencing.

Fences. The American Railway Engineering Association Manual gives specifications for three classes of smooth wire fences 4½ ft. high with wooden posts. Preference is given to smooth wire, but if barbed wire is used, a heavy smooth wire, or a plank at the top of the fence is recommended. For the three classes of smooth wire fence, galvanized No. 9 gage is used throughout except for the top and bottom longitudinal wires of Class 1 which are No. 7 gage. The longitudinal wires are all coiled; the spacing, commencing at the bottom, is Class 1: 3, 4, 5, 6, 7, 8, 9 and 9 in.; Class 2: 5, 6½, 7½, 9, 10 and 10 in.; Class 3: 14, 14 and 14 in. The bottom wire is to be placed above the ground 3, 6 and 12 in., respectively, for the three classes. The stay wires are spaced 12, 22 and 22 in., respectively. Intermediate posts are to be 8 ft. long and not less than 4 in. in diameter at the small end, and end posts 9 ft. long and 8 in. in diameter; round posts are preferred. The posts are to be set with the large end down, the end posts 4 ft. deep and the intermediate ones 3 ft., with spacing from 16½ to 33 ft., depending upon the nature of the ground and the service required. Gates are necessary at farm or private crossings.

In Bulletin No. 144 of the Railway Engineering Association, it is stated that the tendency to use reinforced concrete posts is increasing and that the figures prevailing for the most popular form now on the market are from 18 to 22 cents. The prevailing cost for wood posts of the most durable kinds of timber native to the road is from 12 to 15 cents. Several forms of metal posts are being made, and it is claimed by a large manufacturer that they will have a life of at least 30 years and can be delivered at reasonable distances for 23 cents f.o.b. line of road.

Camp, Track, estimates that under average conditions the labor of building a mile of barbed wire fence four strands high, posts 16 ft. apart, is about 13 days work (10-hr. day); with posts 12 ft. apart, 16 days; with top board and four wires, posts 12 ft. apart, 18 days. For a fence with a different number of wires allow about 8 hours labor for each wire. Experienced fence men working by contract will build about 50 per cent. more fence per day than the same number of ordinary track laborers engaged on the work only a short time each season. The average cost for labor in erecting 22 miles of Page woven wire fence, posts 17 ft. apart and set 3 to 3½ ft. in the ground, was 17.2 cents per rod as shown by the report of the fence gang of a certain railroad. The surface was generally rough and uneven and a great many anchor posts had to be used. The cost stated covered the labor of loading and unloading new material, removing the old fence and piling or burning it, and the time used in moving the fence gang from point to point.

Snow Fences. Where much trouble is experienced from drifting snow, snow fences have been extensively used to protect cuts and other places where snow accumulates. These snow fences may be installed permanently or may be made of the portable type. The standard portable snow fence of the New York State Railways is shown in Fig. 18, from the Electric Railway Journal, 1910.

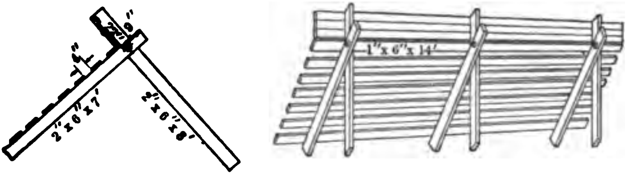


FIG. 18.—N. Y. State Railway's portable snow fence.

Street Railway Roadbed Construction. The construction of roadbed in highways must necessarily differ materially from construction on private right of way, and as the conditions as to highway traffic, pavement, etc., vary so widely, it is not possible to standardize such construction to so great an extent as has been

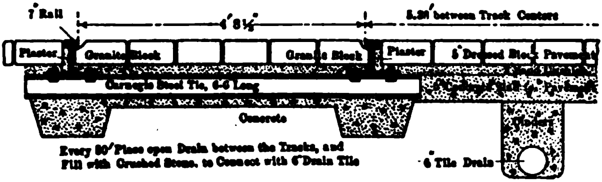

7" Rail
4' 8½"
between Track Centers
Plaster
Granite Block
Granite Block
Plaster
Carnegie Steel Tie, 6-6 Long
Concrete
Every 30' Place open Drain between the Tracks, and Fill with Crushed Stone, to Connect with 6" Drain Tile
6" Tile Drain

FIG. 19.—Standard construction, Cleveland.

done in the case of the private right of way roadbed. Figs. 19 to 40, inclusive, illustrate roadbed construction in streets as practised by various electric railways, including construction with wood ties on ordinary ballast in unpaved streets as well as various

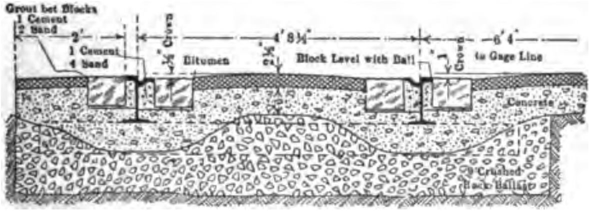


FIG. 20.—Standard construction, San Francisco.

forms of ties and concrete base construction in various forms of paving. For paved streets the type of substructure which is preferred by the largest number of companies seems to be a regular ballasted construction with broken stone, gravel, slag or cinder ballast 6 to 8 in. deep under the ties. Drains are sometimes provided under each track or between tracks. This is used both

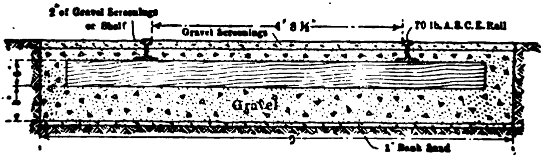


FIG. 21.—Gravel ballast construction, Houston.

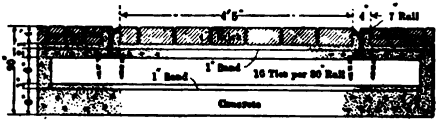


FIG. 22.—Standard construction, Detroit.

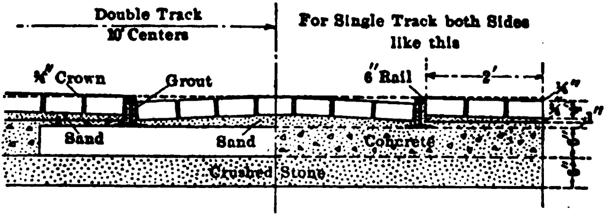


FIG. 23.—Standard construction, Little Rock.

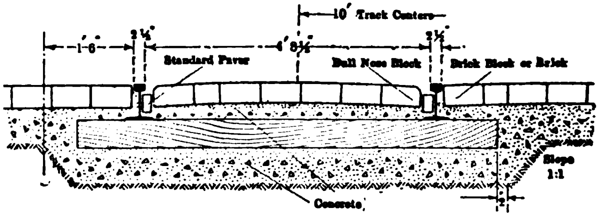


FIG. 24.—Standard construction, Seattle.

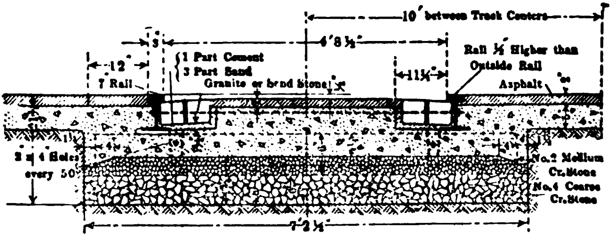


FIG. 25.—Standard construction, Milwaukee.

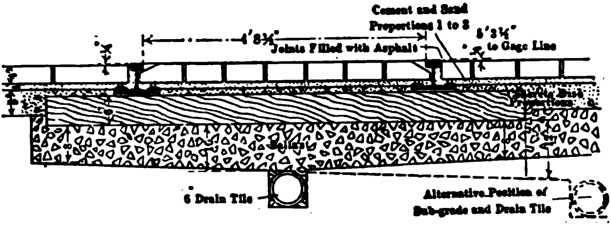


FIG. 26.—Standard construction, Kansas City.

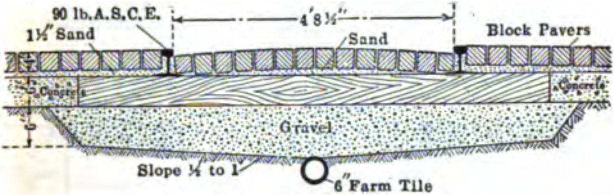


FIG. 27.—Standard of Illinois traction system.

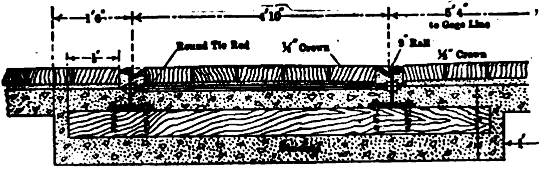


FIG. 28.—Standard construction, St. Louis.

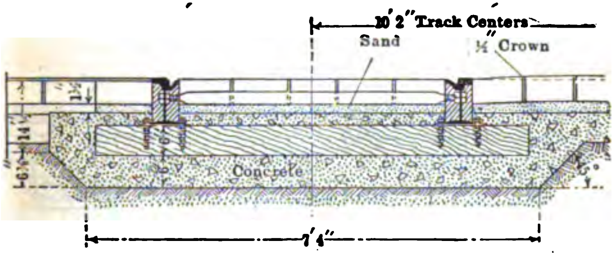


FIG. 29.—Concrete construction, Chicago.

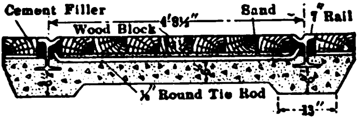


FIG. 30.—Concrete construction, Memphis.

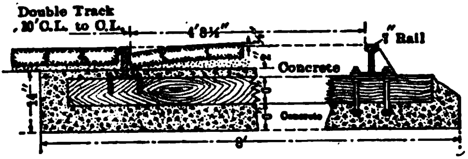


FIG. 31.—Concrete construction, Houston.

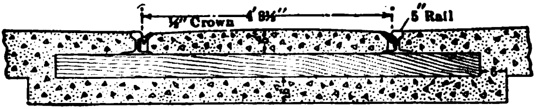


FIG. 32.—T-rail construction, Memphis.

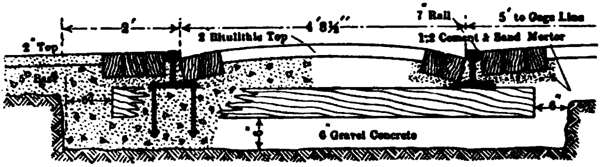


FIG. 33.—T-rail construction, Dallas.

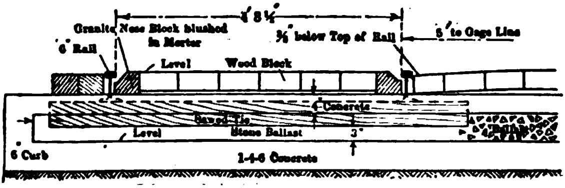


FIG 34.—Standard construction, Toledo.

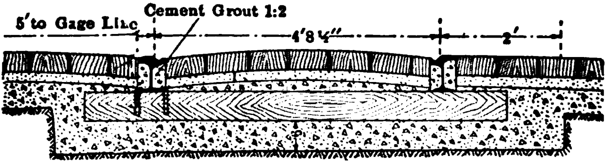


FIG. 35.—Girder rail construction, Dallas.

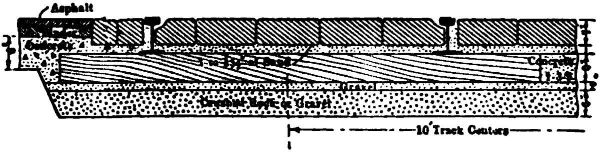


FIG. 36.—Standard construction, Minneapolis.

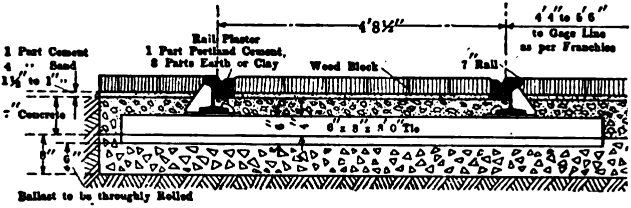

4' 8½"
4' 4" to 6' 6" to Gage Line as per Franchise
Rail Plaster 1 Part Portland Cement, 8 Parts Earth or Clay
1 Part Cement
4 " Sand
1½" to 1" "
Wood Block
7" Rail
7" Concrete
6" x 8" x 8' 0" Tie
8"
6"
Ballast to be throughly Rolled

FIG. 37.—Standard construction, Newark, N. J.

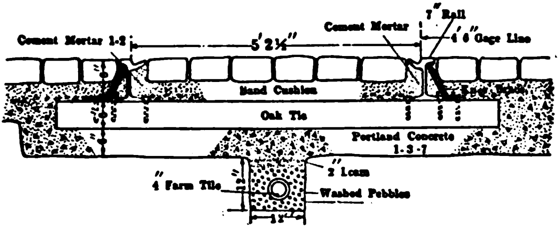


FIG. 38.—Standard construction, Cincinnati.

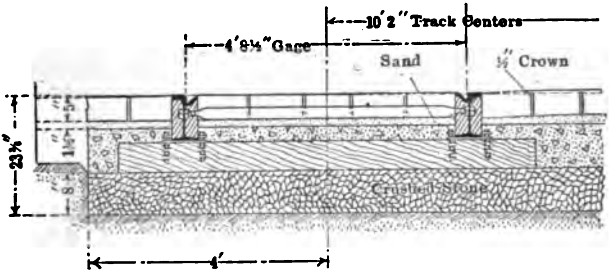


FIG. 39.—Ballast construction, Chicago.

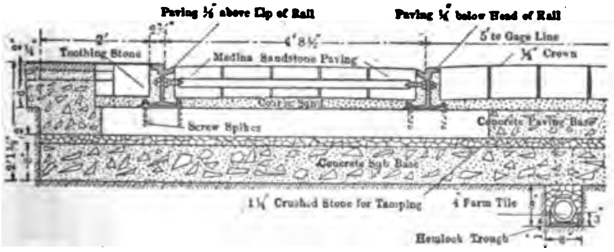


FIG. 40.—Standard construction, Buffalo.

Paving and Care of Streets by Street Railway Companies

The following table from Engineering News, 1911, gives particulars of the requirements of a number of large cities as to paving, repairing and cleaning of streets by street railway companies and also particulars as to track construction and paving materials used.

Railways	Paving material		Flange ways		Railway Co.'s street work			
	Between rails and tracks	Remainder of street	In paved streets	In macadam	Pave	Sweep	Sprinkle	Clear snow
Albany	Asphalt, brick, gran. blk., etc.		Grooved rail		Yes	No	Yes	Yes
Atlanta	Asphalt, brk., gran. blk., bitulith		Grooved girder rail		Yes	No	No	No
Baltimore	Belg. blk., slag-blk., cobble, vit. brick		Tram-head and grooved girder rails		Repairs only	No	Yes	Yes
Chattanooga	Brk., Belg. blk., chert. (no asphalt)	Brk., Belg. blk., chert., asph.	Stretcher brick		Bet. and 1 ft. outside rail	No	No	No
Cincinnati	Asph., brick, wd. gran., tarvia, macadam, bitulith		Grooved rail		Only if Co. disturbs it	No	Yes	Yes
Cleveland	Medina stone, brick (no asph.)	Asph., medina sandstone, brick	Grooved rail		Yes	Yes	Yes	Yes
Columbus	Brick, asph., stone block		Spl. blk. with T-rail		Yes	Yes	Yes	Yes
Denver	Basalt con. with bas block toothing	Asph. or sandstone, brick	Beveled basalt block and T-rail		Bet. and 1 ft. outside rail	No	No	To facilitate operation only
Detroit	Same as remainder	Various	Granite nose block		Yes	No	Yes	Yes
Houston	Mostly brick	Mostly brick	Spec. brk.		Yes	Yes	Yes	No snow
Milwaukee	Gran., block, asph., brick	Asph., brk., Kettle River sandstone	Block set under T-rail head	Mac. under T-rail head	No	No	No	Yes

Paving and Care of Streets by Street Railway Companies.—*Continued*

Railways	Paving material		Flange ways		Railway Co.'s street work			
	Between rails and tracks	Remainder of street	In paved streets	In macadam	Pave	Sweep	Sprinkle	Clear snow
Minneapolis	Gran. block	Gran., asph., creos. block	Nose block	Stone kept away from rail	Yes (all)	Co. pays city	....	....
Mobile	Asph., brick and wood block	....	Nose brick and grooved rail	....	City paves, Co. pays	No	No	No snow
Philadelphia	Gran. block mainly	Asph., brk., gran. brick, macadam	Grooved rail	....	Pays city lump sum yearly	No	No	No
Pittsburgh	Stone, block, brk., asphalt	....	Grooved gir. rail	....	Yes	No	Partly	Yes
Seattle	Asph., brk., sandstone, blk., granite blk.	....	Nose brick	....	All but laying asph.	Some	Some	Some
Washington	Creos. wd., asph. with scoria blk., stretcher Hassam stone,[1] macadam	Asph. with scoria blk. or Hassam stone, stretcher blk.	Grooved rail	Stone graded to bottom of rail head	Yes (see note)	No	No	From track

[1] Hassam stone preferred.

Note: Washington, D. C., the company is required to pay for all paving in and between the tracks and 2 ft. adjacent thereto in all streets. It is not required to sweep, sprinkle or remove snow, but does remove snow from its own tracks. There is no trouble with dirt in the groove of the "Trilby" rail with flaring groove. The old-style full-groove rail is troublesome in snow.

PAVING AND CARE OF STREETS BY STREET RAILWAY COMPANIES.—*Continued*

Railways	Concrete base						
	Under paving	Under width of track	Stringer under rail	Thickness of base or string piece, inches	Ties embedded in concrete	Subgrade rolled	Trouble with dirt or wheel flanges on grooved rail
Albany	Yes	No	No	....	No	Yes	No
Atlanta	Yes	Only with 9-in. Trilby rail in asph.	....	Under rail 10, under tie 4	Only with 9-in. Trilby rail in asph.	Yes	No
Baltimore	Recently	No	No	....	Rarely	....	Some
Chattanooga	Yes	No	Yes	....	No	No	T-girder
Cincinnati	6-in. con.	Yes	Yes	6 to 8 under ties	....	Yes	Dirt collects
Cleveland	Usually	Yes	Yes	10	Yes	No	No
Columbus	Yes	Yes	Yes	Stringer 13, base 12 to 14 high	Largely	Only soft ground	Yes
Denver	Yes	Yes	No	6 bet. ties	Yes	No	No gir. rails
Detroit	Yes	Yes	No	8 in. under ties	Yes	When possible	Yes
Houston	Yes	Yes	No	14 (6 under, 2 over ties)	Yes, in pavt.	No	Yes
Milwaukee	Yes	Yes	No	6 under ties	Yes	No	No gir. rails

Paving and Care of Streets by Street Railway Companies.—*Continued*

Railways	Concrete base						
	Under paving	Under width of track	Stringer under rail	Thickness of base or string piece, inches	Ties embedded in concrete	Subgrade rolled	Trouble with dirt or wheel flanges on grooved rail
Minneapolis...	Yes	No	Ties on bal. con. bet. ties	....	Concrete bet.	When soft	T-girder
Mobile........	Yes	No	String 20 wide, 44 L. ties 48 apt.	Str. 8	No	Tamped	No
Philadelphia...	In bus sec.	Not with ties	Yes	....	No	When soft	No
Pittsburgh....	If required by city	Not under track	No	....	Only when con. base under paving	Yes	No
Seattle........	Yes	Yes	Yes, in string construction	Base 5 strg., 12 deep, 16 wide	In paving	When possible	Yes
Washington...	Yes, except macadam	Only with conduit const. with macadam, C. I. yokes	....	....	No	For surface track	See note page 39.

with and without a paving base. The type of substructure at present next to the above in preference and use appears to be a solid concrete construction either with steel ties, 4-ft. centers, or wood ties, 2-ft. centers, and concrete 4 to 8 in. under the ties, extending up between the ties to provide a paving base. The tendency, however, is to leave the type with a solid concrete foundation and rails fastened to it, for more flexible types. The reduction of noise is a factor as well as the maintenance of track, pavement and equipment. A type of substructure which has recently come into use is that with the ties resting on 2 to 3 in. gravel or broken stone on top of a 6-in. concrete slab; a concrete paving base being provided between and over the tops of the ties.

Characteristics of Track Construction in Paved Streets. The figures on pages 33 to 37, inclusive, the tables on pages 38 to 41, inclusive, as well as the following from Electric Railway Journal, 1913, show details of the track construction in paved streets in a number of North American cities.

CHARACTERISTICS OF TRACK CONSTRUCTION IN PAVED STREETS

City	Roadbed under ties	Ties		
		Spac'g	Kind	Size
Baltimore....	6" ballast under ties....	2'0"	Wood......	6"×8"×8'
Birmingham.	6" 1:3:6 slag concrete...	3'4"	Creosoted pine.	6"×8"×7'6"
Boston.......	6" trap rock—1:2:5 con., width 3½", cr.-r'k cushion.	2'0"	Long-leaf pine.	6"×8"×8'
Buffalo......	8" 1:3:5 grav.—concrete with 2" sand cushion.	2'0"	Long-leaf pine.	6"×8"×7'
Chicago......	8" crushed-stone ballast.	2'0"	Yellow pine & creosoted oak.	6"×8"×7'
Cincinnati....	6" 1:3:7 rock conc., 4" farm drain in center.	2'0"	White oak..	6"×8"×8'
Cleveland....	6" 1:6 gravel conc. under tie & 12" under rail.	4'0"	Carnegie steel.	6'6" long
Dallas.......	6" 1:7 gravel concrete, 6" 1:3:6 rock concrete.	3'0"	Hd. pine, drop anchs. ev. 2d tie.	6"×8"×7'
Detroit......	8" 1:2:4 grav. conc., 1" sand cushion under ties	3'0"	White oak.	6"×10"×6'8"
Harrisburg...	6" cr. r'k ballast under ties.	3'0"	Chestnut...	6"×8"×7'6"
Houston.....	6" 1:3:6 rock concrete..	5'0"	Pecky cypress. Anc. bet. ties.	6"×8"×7'
Ill. Trac.....	8" grav. ballast........	2'0"	Creo. white oak.	6"×8"×8'
Indianapolis..	6" to 10" 1:2½:5 gravel concrete under ties.	2'0"	White oak.	6"×8"×8'
Kansas City..	8" to 12" crushed rock ballast under ties. Tile drain.	20"	White oak.	6"×8"×8'
Little Rock ..	6" crushed stone.......	2'0"	Creosoted pine, sawed	6"×8"×8'
Louisville....	6" crushed stone concrete.	2'	Steel ties, oak ties.	4¼"×6'6" 6"×8"×8'
Los Angeles..	....	20"	Redwood...	6"×8"×8'
Milwaukee...	6" No. 4 crushed rock and 3¾" No. 2 crushed rock.	2'0"	Long-leaf yel. pine, wh. oak.	6"×8"×7'
Memphis.....	6" crushed rock concrete	5'0"	Creo. pine ties.	6"×8"×8'

CHARACTERISTICS OF TRACK CONSTRUCTION IN PAVED STREETS

City	Roadbed under ties	Ties		
		Spac'g	Kind	Size
Minneapolis..	6" rock ballast with 2" gravel under ties.	2'0"	Oak or pine creosoted.	6"×8"×8'
Montreal.....	8" 1:3:6 rock concrete, 1" sand cushion under ties.	2'0"	Pine and cedar.	6"×8"×8'
Newark......	6" crushed rock or slag under ties.	2'0"	Long-leaf pine, creosoted.	6"×8"×8'
New Haven..	Natural gravel ballast in subsoil.	2'0"	White oak and chestnut.	6"×8"×8'
Philadelphia.	18"× 19" concrete stringer.	4'0"	Cast-iron chair	....
Pittsburgh...	8" stone ballast under ties.	2'0"	....	6"×8"×8'
Portland, Ore.	6" to 8" gravel ballast under ties with tile drain.	2'0"	Fir........	7"×9"×8' 6"×10"×6'
Richmond....	6" concrete............	8'0"	Carnegie...	4¼"×6'8"
Seattle.......	6" 1:4:7 concrete.......	18"	Washington fir.	6"×8"×7'
San Francisco	9" stone ballast under ties.	2' "	Redwood...	. 6"×8"×8'
St. Louis.....	6" 1 : 3¼ : 6½ rock concrete under ties.		White oak.	6"×8"×8'
Springfield...	9"×22" concrete beam	5'0"	Steel.......	4¼"×6'8"
Toledo.......	6" 1:4:6 concrete and 3 stone ballast.	2'0"	Sawed white oak.	5"×8"×7'
Toronto......	6" or 7½" 1:3:7 rock concrete under ties.	5'0" or 2'6"	Carnegie steel, cedar & pine.	7" long 6"×8"×8'
Vancouver...	6" 1:3:6 gravel concrete, 1" sand cushion under ties.	2'0"	Fir........	6"×8"×8'
Winnipeg....	3" crushed stone, 6" 1:3:5 concrete under ties	2'0"	Fir.........	6"×8"×8'
Washington..	5" crushed rock........	30"	Chestnut...	6"×8"×8'

CHARACTERISTICS OF TRACK CONSTRUCTION IN PAVED STREETS. —*Continued*

City	Rail		Joints			
	Type	Wt.	Type	Drill'g	Lgth.	Bolts
Baltimore....	9" & 7" gird. groove	103	Riveted-welded	10-hole	32"	1" rivets
Birmingham .	7" T-rail	80	Continuous....	4-hole	24"	⅞"
Boston......	9" girder	132	Electric-welded	None	.....	None
	7" girder	116				
Buffalo......	9" girder groove	124	Continuous....	4-hole	24"	1"
Chicago......	9" girder groove	129	Electric-welded	None	.....	None
Cincinnati...	9" girder groove	140	Cast welded....	....	13"	....
Cleveland....	7" T-rail	95	Clark joint....	8-hole	30"	1⅛"
Dallas.......	7" T-rail	80	Continuous....	6-hole	26"	1"
	7" girder groove	103				
Detroit......	7" T-rail	91	Cast welded....	None	.....	None
Harrisburg...	9" tram	125	Continuous....	6-hole	26"	⅞"
Houston.....	A.S.C.E.	80	Bonzano continuous	6-hole	26"	1"
	7" T-rail	80		6-hole	26"	1"
Ill. Trac.....	A.S.C.E.	90	Continuous....	6-hole	26"	⅞"

CHARACTERISTICS OF TRACK CONSTRUCTION IN PAVED STREETS. —*Continued*

City	Rail		Joints			
	Type	Wt.	Type	Drill'g	Lgth.	Bolts
Indianapolis	7″ T-rail	91	Cast welded and continuous	....	.....	None
	9″ tram	95				
Kansas City .	A.S.C.E.	100	Continuous....	4-hole	24″	1″
	9″ Trilby	109				
Little Rock...	6″ T-rail	72	Angle-bar continuous	6-hole	34″	⅞″
	7″ tram gird.			4-hole	24″	⅞″
Louisville....	9″ Trilby	106	Bars..........	....	.....	1″ but. h'd
Los Angeles..	9″ Trilby	116	Continuous and thermit	....	.....	....
	7¼″ T-rail	87				
Milwaukee...	7″ T-rail	95	Cast welded and bar	6-hole	28″	1⅛″
Memphis....	T and 7″ Trilby	80 105	Cast and bar...	8-hole	34″	1″
Minneapolis..	7″ T-rail	91	Cast welded....	1-hole	.....	None
Montreal....	7″ Trilby	116	Continuous....	6-hole	26″	1″
Newark......	7″ Trilby	116	Bonzano continuous	4-hole	24″	⅞″
New Haven..	7″ T-rail	95	Continuous bar	4-hole	24″	⅞″
	9″ girder grooved	125		12-hole	32″	
Philadelphia .	9″ Trilby	141	Nichols joint...	None	.....	1″ rivets
Pittsburgh...	9″ Trilby	125	Bars with reamed holes	....	.....	Machin'd
Portland, Ore.	7″ groove	95	Continuous....	4-hole	24″	1″
	7″ T-rail	80				
	6″ T-rail	72				
Richmond....	9″ girder groove	114	Electric weld...	....	.....	....
Seattle.......	7″ T-rail	90	Continuous....	6-hole	26″	1″
San Francisco	9″ Trilby	106	Bars	6-hole	26″	1″
St. Louis.....	9″ T-rail	100	Nichols joint...	....	.....	....
	7″ Trilby	132				
Springfield...	7″ T-rail	70	Continuous....	6-hole	26″	⅞″
Toledo.......	6″ Dudley	100	Angle bars.....	4-hole	24″	1″
Toronto.....	7″ T-rail	90	Continuous....	6-hole	26″	1″
	7″ T-rail	80	Continuous....	6-hole	26″	1″
Vancouver...	7″ T-rail	91	Continuous....	6-hole	26″	1″
Winnipeg....	7″ T-rail	80	Continuous....	6-hole	26″	1″
Washington...	A.S.C.E. titan.	80	Continuous....	6-hole	30″	⅞″

CHARACTERISTICS OF TRACK CONSTRUCTION IN PAVED STREETS. —*Continued*

City	Spikes	Bonds	Tie rods	Rail braces and tie plates
Baltimore......	Screw	None........	⅜″ × 2″, 6′ centers.	Tie plates.
Birmingham....	9/16″ × 5½″	Com. ter. and ball.	None.......	Tie plate and rail brace 6′8″
Boston.........	½″ × ¾″ × 6⅛″ screw	None.........	1″ r'd & 2¼″ × 13/32″ flat, 5′ centers.	Tie plates on all ties.
Buffalo........	Screw ½″ × ¾″ × 6⅛″	2-4/0 compressed term'l.	5/16″ × 2″, 6′ centers.	Plates on all ties.
Chicago........	Screw ½″ × ¾″ × 6⅛″.	None........	5/16″ × 2″, 6′ centers.	Tie plates ¼″ × 6″ × 10″
Cincinnati......	9/16″ × 5½″	None........	None........	Rail brace at fourth tie.
Cleveland......	Bolt and clip	None........	⅜″ × 2″, 5′ centers.	None.

CHARACTERISTICS OF TRACK CONSTRUCTION IN PAVED STREETS.
—*Continued*

City	Spikes	Bonds	Tie rods	Rail braces and tie plates
Dallas	9/16" × 5½"	2–9" crown pin	None	Brace plates every third tie.
Detroit	9/16" × 5½"	None	3/8" × 1½", 6' centers.	None.
Harrisburg	9/16" × 5½"	Comp'd term'l	3/8" × 2", 10' centers.	None.
Houston	Screw	2–4/0 pin driven.	None	Railbrace every 10'0".
Ill. Trac.	9/16" × 5½"	Comp. term.	None	None.
Indianapolis	9/16" × 5"	Brazed and comp. term'l.	3/8" × 2"	None.
Kansas City	9/16" × 5½" Screw 3/4" × 5½"	Comp. term'l. and soldered.	7/8" round	Tie plates with screw spike.
Little Rock	9/16" × 5½"	2–4/0 sold'r'd	None	None.
Louisville	9/16" × 5½"	2 flexible, compress'd term'l	Flat, 2" × 3/8" & 7/8" round.	None.
Los Angeles	9/16" × 5½"	....	....	Every fourth tie.
Milwaukee	3/4" × 7/8" Screw	....	2" × 5/16", 6' centers.	None.
Memphis	9/16" × 5½"	Com. ter. and brazed.	7/8" round	None.
Minneapolis	9/16" × 5½"	None	3/8" × 1½", 10' centers.	None.
Montreal	9/16" × 5½"	Electric brazed.	13/16" rod, 6' centers.	None.
Newark	9/16" × 5½"	Comp. term'l.	None	Tie plates on every 2d tie.
New Haven	9/16" × 5½"	....	None	Only on curves.
Philadelphia	Bolt and clip	None	None	None.
Pittsburgh	9/16" × 5½"	Comp. term'l & ther. welded	5/8" × 2"	....
Portland, Ore.	9/16" × 5½"	Comp. term'l	None	None.
Richmond	Lugs and T-bolts.	None	None	Tie fast. and rail brace.
Seattle	9/16" × 5½"	4/0 & 500,000 c.m., sold'r'd.	On curves 8' cen. At j'ts 30" cen.	6 8" × 10" × 3/8" at joints only.
San Francisco	9/16" × 5½"	7/8" comp. ter.	7/8" rod, 10' cen.	None.
St. Louis	Screw	None	7/8" rods, 6' cen.	Tieplate with screw spikes.
Springfield	Lugs & bolts	None	None	None.
Toledo	9/16" × 5½"	1-8", 4/0, braz.	None	None.
Toronto	Bolt and clip 9/16" × 5½"	Electric welded on rail head	7" rods, 6' centers.	None.
Vancouver	9/16" × 5½"	Comp. term'l and soldered.	3/8" × 2", 6' centers.	None.
Winnipeg	9/16" × 5½"	4/0 soldered to rail head.	None	None.
Washington	9/16" × 5½"	2–4/0 pin terminal.	1½" × 3/8"	None.

T-rail Sections. The American Society of Civil Engineers and the P. M. Dudley sections have probably been most used in steam railroad construction. The former is shown in Fig. 41 and the latter in Fig. 44, while the Standard P. S. section is shown in Fig. 45 for a 100-lb. rail. For the first, 42 per cent. of the material is in the head, 21 per cent. in the web and 37 per cent.

Standard T Rails

(Letters refer to Figs. 41, 42, 43)

	A	B	C	D	E	F	G	Percentage of metal				
Pounds per yard	Height of rail	Width of base	Width of head	Thickness of web	Depth of head	Height of web	Height of flange	Head	Web	Base	Moment of inertia about X – X	Y
				American Society of Civil Engineers								
100	5 3/4	5 3/4	2 3/4	9/16	1 45/64	3 5/64	31/32	42	21	37	43.8	2.8
95	5 9/16	5 9/16	2 11/16	9/16	1 41/64	2 63/64	15/16	42	21	37	38.6	2.7
90	5 3/8	5 3/8	2 5/8	9/16	1 19/32	2 55/64	59/64	42	21	37	34.0	2.5
85	5 3/16	5 3/16	2 9/16	9/16	1 35/64	2 3/4	57/64	42	21	37	30.0	2.5
80	5	5	2 1/2	35/64	1 1/2	2 5/8	7/8	42	21	37	26.2	2.4
75	4 13/16	4 13/16	2 15/32	17/32	1 27/64	2 35/64	27/32	42	21	37	22.9	2.4
70	4 5/8	4 5/8	2 7/16	33/64	1 11/32	2 15/32	13/16	42	21	37	19.6	2.2
65	4 7/16	4 7/16	2 13/32	1/2	1 9/32	2 3/8	25/32	42	21	37	16.9	2.2
60	4 1/4	4 1/4	2 3/8	31/64	1 7/32	2 17/64	49/64	42	21	37	14.5	2.1
55	4 1/16	4 1/16	2 1/4	15/32	1 11/64	2 11/64	23/32	42	21	37	11.9	2.0
50	3 7/8	3 7/8	2 5/8	7/16	1 1/8	2 1/16	11/16	42	21	37	9.8	1.9
45	3 11/16	3 11/16	2	27/64	1 1/16	1 31/32	21/32	42	21	37	8.0	1.8
40	3 1/2	3 1/2	1 7/8	25/64	1 1/64	1 55/64	5/8	42	21	37	6.6	1.7
				American Railway Engineering Association—Series A								
100	6	5 1/2	2 3/4	9/16	1 9/16	3 3/8	1 1/16	36.9	23.4	39.7	48.94	2.75
90	5 5/8	5 1/8	2 9/16	9/16	1 15/32	3 5/32	1	36.2	24.0	39.8	38.70	2.54
80	5 1/8	4 5/8	2 1/2	33/64	1 7/16	2 23/32	31/32	38.8	21.0	40.2	28.80	2.31
70	4 3/4	4 1/4	2 3/8	1/2	1 11/32	2 1/2	29/32	39.3	21.8	38.9	21.05	2.20
60	4 1/2	4	2 1/4	15/32	1 15/64	2 29/64	13/16	37.7	24.1	38.2	15.41	2.13
				American Railway Engineering Association—Series B								
100	5 41/64	5 9/64	2 21/32	9/16	1 45/64	2 55/64	1 5/64	40.2	19.2	40.6	41.3	2.63
90	5 17/64	4 49/64	2 9/16	9/16	1 39/64	2 5/8	1 1/32	40.1	19.2	40.7	32.3	2.45
80	4 15/16	4 7/16	2 7/16	35/64	1 15/32	2 15/32	1	38.8	19.5	41.7	25.1	2.27
70	4 35/64	4 3/64	2 3/8	33/64	1 23/64	2 17/64	59/64	40.1	19.5	40.4	18.6	2.16
60	4 3/16	3 11/16	2 1/8	31/64	1 1/4	2 1/16	7/8	38.8	19.4	41.8	13.3	1.95

in the base. The height and width of base arē the same, while for the other types the height is greater. This is an advantage in rolling, as the base will not cool so rapidly with reference to the head, but the ties will be cut more rapidly owing to the reduced bearing and greater leverage under side thrust unless tie plates are used. The head is thin and wide on each to maintain more equal temperatures in the different parts in rolling and to reduce the unit pressure between wheel and rail. The recent tendency has been to thicken the base still further to equalize temperature in rolling.

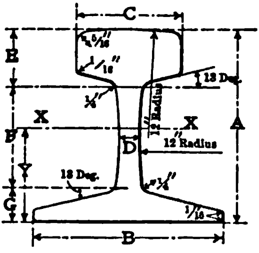


Fig. 41.—A.S.C.E. rail section.

Figs. 41, 42 and 43 and the accompanying table show the various A.S.C.E. and A.R.E.A. standard T-rail sections.

In order to provide sufficient depth between the street surface and top of tie, in street railways, it may be necessary to employ a high section of rail. The Am. El. Ry. Eng. Assn., 1909, recommends for T-sections the rails shown by Fig. 46 to be used where the type of pavement will permit (as in macadam or other shallow pavement); for the heavy service in connection with deep pavements, a section as shown by Fig. 47, weighing about 100 lb. per yard; and for light service with deep pavements, a section as shown by Fig. 48, weighing about 80 lb. per yard.

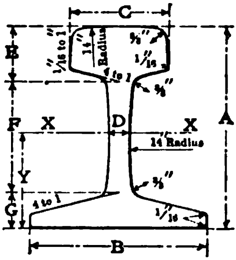


FIG. 42.—Am. Ry. Eng. Assn. series A rail section.

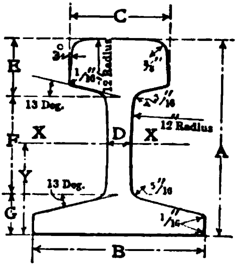


FIG. 43.—Am. Ry. Eng. Assn. series B rail section.

Girder Rail Sections. The Am. El. Ry. Eng. Assn. recommends the use of girder rail for track construction for heavy service in connection with deep block pavements on streets where traffic is confined to the railway strip or where the railway strip is continually used by vehicles, which conditions exist only in cities of the largest class. The Association in 1913 adopted as standard for such rails the following sections: the 9-in. girder grooved rail shown by Fig. 49; the 9-in. girder guard rail shown by Fig. 51; the 7-in. girder grooved rail shown by Fig. 50; and the 7-in. girder guard rail shown by Fig. 52. At the same time the Association adopted as recommended

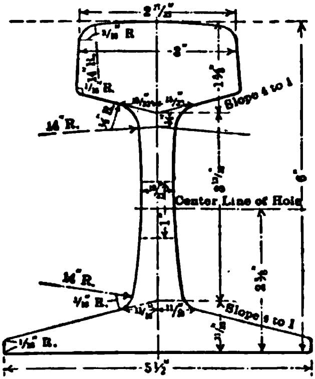


FIG. 44.—P. M. Dudley 100-lb. rail section.

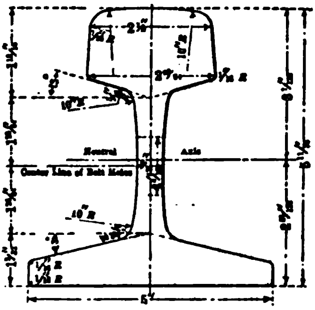
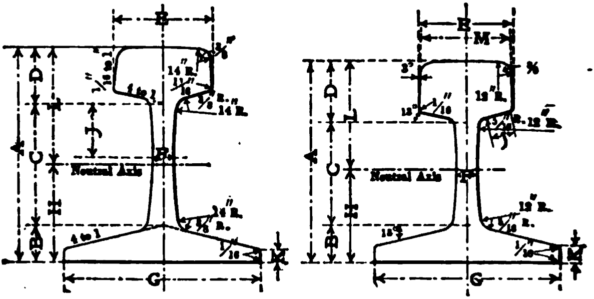


FIG. 45.—Pennsylvania system 100-lb. rail section.



Series 1.   Series 2.

Type of rail	Series 1			Series 2		
Weight per yard	80	90	100	80	90	100
Height A	5 1/8"	5 5/8"	6"	4 15/16"	5 17/64"	5 41/64"
B	31/32"	1"	1 1/16"	1"	1 1/32"	1 5/64"
C	2 23/32"	3 5/32"	3 3/8"	2 15/32"	2 5/8"	2 55/64"
D	1 7/16"	1 15/32"	1 9/16"	1 15/32"	1 39/64"	1 45/64"
Width of head E	2 1/2"	2 9/16"	2 3/4"	2 7/16"	2 9/16"	2 21/32"
Thickness of web F	31/64"	9/16"	9/16"	35/64"	9/16"	9/16"
Width of base G	4 5/8"	5 1/8"	5 1/2"	4 7/16"	4 49/64"	5 9/64"
H	2.31"	2.54"	2.75"	2 35/128"	2 57/128"	2 5/8"
J	1 1/8"	1 1/4"	1 1/2"	49/64"	43/64"	49/64"
K	3/8"	3/8"	3/8"	31/64"	31/64"	31/64"
L	2.82"	3.09"	3.25"	2 85/128"	2 105/128"	3 1/64"
M	......	......	......	2 11/32"	2 15/32"	2 9/16"
Area of head, sq. in.	3.05	3.20	3.64	3.07	3.56	3.95
Area of web, sq. in.	1.65	2.12	2.29	1.54	1.70	1.89
Area of base, sq. in.	3.16	3.50	3.91	3.30	3.61	4.01
Total area, sq. in.	7.86	8.82	9.84	7.91	8.87	9.85
Area of head, per cent.	38.8	36.2	36.9	38.8	40.1	40.2
Area of web, per cent.	21.0	24.0	23.4	19.5	19.2	19.2
Area of base, per cent.	40.2	39.8	39.7	41.7	40.7	40.6
Moment of inertia	28.80	38.70	48.94	25.1	32.3	41.3

FIG. 46.—Am. El. Ry. Eng. Assn. T-rail sections for use in macadam or other shallow paving.

designs the joint plates for use with the 9-in. girder rails as shown by Fig. 53, and for the 7-in. girder rails as shown by Fig. 54. The 9-in. girder grooved and girder guard rail sections shown in Figs. 49 and 51 will fish with P. S. Co., Secs. 125–273 and 151–283 and L. S. Co. Secs. 125–427, 132–440 and 150–441.

Grooved Rail Section for M.C.B. Flanges. Fig. 55 shows a 127-lb., 7-in. grooved rail section which was designed for use on the lines of the Pacific Electric Railway in order to permit movement of M.C.B. equipment over tracks in paved streets.

Special Rail Head Section for Curves. Special rails for curves have been designed mainly to give additional metal available for wear. The Manning rail, tried some years ago on the Baltimore & Ohio R. R., had 1/32 in. of additional metal on the inner side of the head and 1/32 in. less on the outer side. The special

110-lb. rail of the Lehigh Valley R. R. has the head slightly wider and considerably deeper than that of the standard rail. The special feature of the so-called "Frictionless" rail (Fig. 56) is a very narrow head, and its purpose is to reduce the slip of the inside wheel, which takes place in compensating for the greater length of travel of the wheel on the outside rail. It is claimed that there is a diminution of friction and resultant wear to both the outer and inner (frictionless) rails and the wheel flanges, while the reduced friction gives a freer and smoother passage of the wheels, with a reduction in power required to handle a given tonnage.

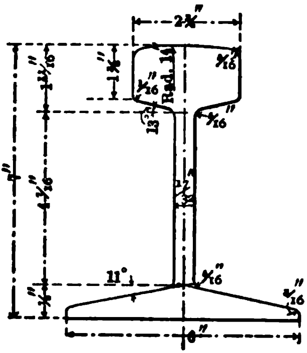


FIG. 47.—Am. El. Ry. Eng. Assn. 100-lb., 7-in. T-rail.

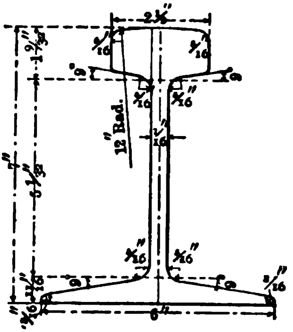


FIG. 48.—Am. El. Ry. Eng. Assn. 80-lb., 7-in. T-rail.

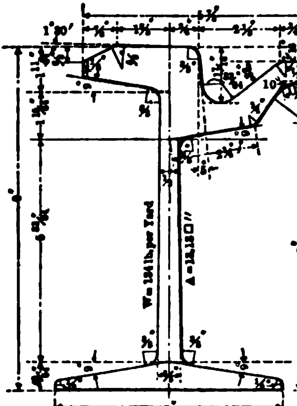


FIG. 49.—Am. El. Ry. Eng. Assn. 9-in. girder grooved rail.

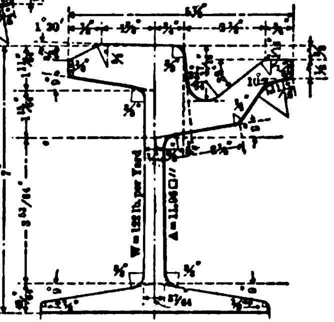


FIG. 50.—Am. El. Ry. Eng. Assn. 7-in. girder grooved rail.

On the Boston Elevated Ry., the "frictionless" rail has been laid on several curves, ranging from 9 deg. to 57 deg., the length of rail used being from 116 to 482 ft. The rail weighs 79½ lb. per yard and is used with the 85-lb. A.S.C.E. section. Both are of open-hearth steel, treated with ferro-titanium, with chemical composition as follows: carbon, 0.80 to 0.95 per cent.; phosphorus, under 0.04 per cent.; silicon, 0.10 to 0.20 per cent.; manganese,

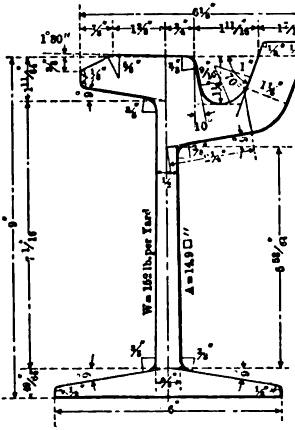


FIG. 51.—Am. El. Ry. Eng. Assn. 9-in. girder guard rail.

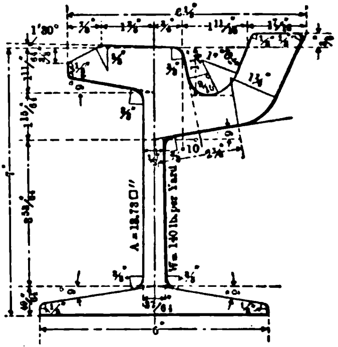


FIG. 52.—Am. El. Ry. Eng. Assn. 7-in. girder guard rail.

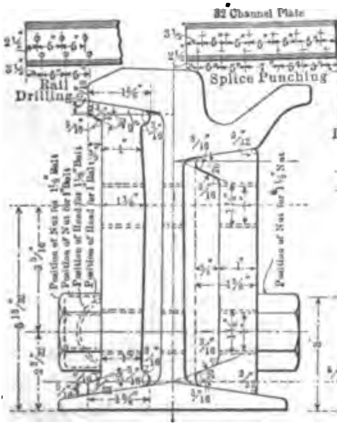


FIG. 53.—Joint plates for Am. El. Ry. Eng. Assn. 9-in. girder rails.

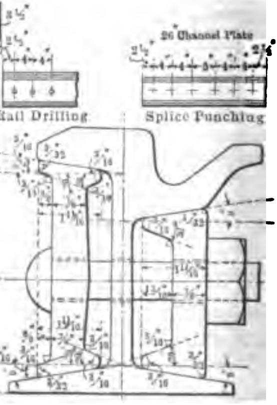


FIG. 54.—Joint plates for Am. El. Ry. Eng. Assn. 7-in. girder rails.

0.65 to 0.90 per cent.; metallic titanium, 0.10 per cent.; sulphur, 0.03 to 0.05 per cent. Information as to the service is from H. M. Steward, Chief Engineer of Maintenance of Way. On account of the short length of these curves it has not been possible to obtain accurate tests as to the increase or decrease in power consumption used by a train in going around the curves, but it is known that less power is required than when the curves were laid with the 85-lb. rail. In some instances where power was required to pass a curve laid with the 85-lb. rail, it is now possible to coast through the curve. It is not found that the narrow-headed rail decreases the braking power of the trains. As an example of the experience with this rail, the curve at Causeway and Haverhill St. may be taken. This has a radius of 90 ft. on the center line, and about 297 ft. of the "frictionless" rail was laid on the inside of the curve in 1912. The conditions on this curve have been as follows: On the inside of the curve, the 85-lb. A.S.C.E. rails of open-hearth ferro-titanium steel were removed Nov. 16, 1912, after a life of 262 days, with a wear of 0.029 ft., the removal following because of corrugations. The 79-lb. "frictionless" rails of the same steel, laid on the above date, were examined on Aug. 26, 1913, after 283 days' service. The wear was 0.036 ft., while there was very little corrugation. The permissible amount of wear is 0.045 ft., and the life of this rail therefore was estimated at 354 days, or 35 per cent. more than the actual life of the former ordinary rails. On the outside of the curve, the 85-lb. rail showed a wear of 0.039 ft. during the 262 days' life of the 85-lb. ordinary rail on the inside, while it was 0.040 ft. during the 283 days' service of the 79-lb. special rail.

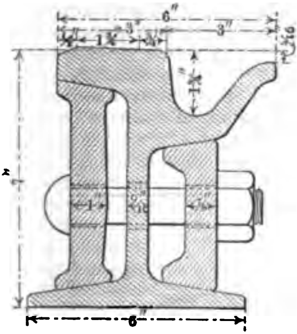


Fig. 55.—Pacific Electric grooved rail for M.C.B. flanges.

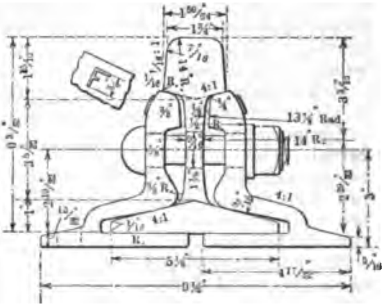


Fig. 56.—Special "frictionless" rail for inside of sharp curves; So. Pac. Ry.

T-, Grooved or Tram Sections of Rail Head. From an operating standpoint T-rail is greatly to be preferred over other types of head, even for city streets, the flange groove being provided for by means of special paving blocks, shown for example in Figs. 19, 24, 25, 26, 27, 31, 32, 33, 34, 36, 57, 58. As a heritage from the old tram rail, many cities still insist upon a tram section of head, while others require a full or partial groove section, similar to Figs. 49 and 51. The T-rail is designed on better mechanical lines and may be more satisfactorily fitted with joints. It has a longer life under equal traffic and the flangeway is more suitable for varying wheel flanges. Many installations of T-rail in paved streets have satisfactorily met local conditions and several cities are requiring the adoption of high T-rails in replacement of tram and girder grooved rails.

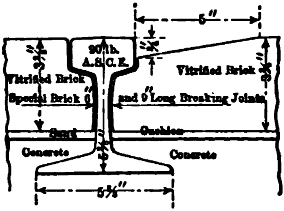


FIG. 57.—Special paving blocks.

Disadvantages of Tram or Groove Sections. A wearing away of the rail head of such sections finally allows wheels to run on their flanges. Such wearing or a filling up of the groove with dirt greatly decreases adhesion. These sections also tend to invite wagon traffic on to the railway tracks, and to interfere with the turning out of horse-drawn vehicles which are traveling on the railway tracks. It is also difficult to design such sections so that they may be rolled and preserve a proper distribution of the weight through the web to the base of the rail. Further, the usual size of groove restricts wheel flanges to smaller maximum dimensions than would otherwise be desirable.

Rail Length. The standard length has changed from 30 to 33 ft. after experiments with lengths of 45 and 60 ft.

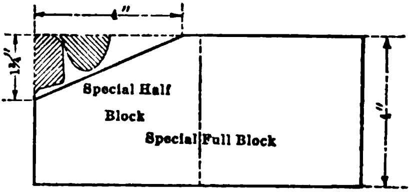


FIG. 58.—Special paving blocks.

Composition of Rail Metal. The quality of the metal in the finished rail will depend upon the chemical composition, the temperature of rolling and the work put upon the metal during rolling. The chemical composition, to be determined from drillings taken from the ladle test ingot, is to be as follows in the Am. Ry. Eng. Assn.'s specifications for carbon steel rails, 1912:

Elements, per cent.	Bessemer Process 70 lb. and over, but under 85 lb.	Bessemer Process 85–100 lb., inclusive	Open-hearth Process 70 lb. and over, but under 85 lb.	Open-hearth Process 85–100 lb., inclusive
Carbon	0.40 to 0.50	0.45 to 0.55	0.53 to 0.66	0.63 to 0.76
Manganese	0.80 to 1.10	0.80 to 1.10	0.60 to 0.90	0.60 to 0.90
Silicon	not over 0.20	not over 0.20	not over 0.20	not over 0.20
Phosphorus	not over 0.10	not over 0.10	not over 0.04	not over 0.04

The Am. El. Ry. Eng. Assn. recommends the following chemical composition to be determined from drillings taken from the test ingot at not less than ⅛ in. beneath the surface:

Per cent.	Class A	Class B
Carbon	0.60 to 0.75	0.70 to 0.85
Manganese	0.60 to 0.90	0.60 to 0.90
Silicon	not over 0.20	not over 0.20
Phosphorus	not over 0.04	not over 0.04

Carbon increases hardness and tensile strength and decreases ductility. The specified increase with weight of rail is probably partly due to a higher temperature during rolling and to less work per pound of metal in the process. The manganese, according to Campbell, combines in part with the dissolved oxygen and passes off with the slag as an oxide when added as ferro-manganese just before pouring. It is thus easier to add spiegel iron than ordinary pig iron to increase carbon since the manganese of the former prevents its oxidation. Manganese also tends to prevent the coarse crystallization due to phosphorus and sulphur and raises the critical temperature to which it is safe to heat the steel, for just as it resists the separation of the crystals in cooling from a liquid, so it opposes their formation when a high temperature increases molecular mobility. The effect of silicon is small although in manufacture it acts like manganese as a flux and tends to prevent injury by oxidation. Phosphorus tends to produce coarse crystallization and hence lowers the finishing temperature in order to prevent the formation of a crystalline structure during cooling. Its effect when cold, up to about 0.12 per cent., is to increase strength and hardness, but it renders the steel brittle under shock and should be kept at the lowest practicable limit. In the Bessemer process as employed in this country, an acid lining is used in the converter and this prevents burning out either phosphorus or sulphur. The limit is thus fixed by that of the available ores. In the open-hearth method a basic lining is used and this permits the conversion of the phosphorus into a slag with lime, and the sulphur with lime and manganese ore. The basic open-hearth method thus allows the use of cheaper ores and the reduction of phosphorus and sulphur to low limits. It also furnishes a more uniform product as the melt can be sampled and proportions corrected if found desirable before pouring. The open-hearth rail is coming into use; the increased cost is about $2 per ton.

Alloyed Steel Rails. The following comments are from the Committee on Way Matters, Am. El. Ry. Eng. Assn. (1912). The treatment of steel for rails with various alloys has been a question of study and experiment for several years, the chief object being to prolong the life of rails by the addition of hardening and toughening qualities, preserving at the same time the ductility necessary to insure freedom from brittleness. Important limitations are at the very outset imposed—primarily, the cost of the finished rails and secondly, the odd-shaped or unbalanced sections of rails—which preclude the possibilities of heat treatment, and matters which prevent as rapid development of the subject as would otherwise be possible. The foregoing are the common methods used in attaining the desired result, which is a moderate priced, long-lived rail of any section immediately available in any quantity. It is only necessary to take up the subject of titanium, manganese and nickel-chrome rails, for while there are various other known alloyed steels, their use in rails with the limitations mentioned makes their consideration here unnecessary. Girder and high T-, as well as standard sections, can be easily rolled from the following special steels possessing the general characteristics mentioned.

Kind	Steel containing	General properties anticipated
Titanium	0.1 per cent. metallic titanium.	Less segregation, cleaner metal, hence, longer life.
Nickel	3.5 per cent. nickel	Increased life.
Nickel chrome	Containing varying percentages—nickel and chromium.	Increased life by being tough and hard.
Manganese	About 12 per cent. manganese.	Very tough and hard, cannot be easily cut or drilled, wears slowly.
Electric	Made in electric furnace.	Very clean steel, free from impurities, thus adding life.
High silicon	About 0.35 per cent. silicon.	Increased life. Much used in England.

Ferro-titanium Steel. The addition of the alloy ferro-titanium to either Bessemer or open-hearth steel is to-day the most common method of seeking to prolong the life of steel rails without materially increasing their cost. The alloy is, as the name indicates, composed chiefly of iron and titanium, the latter being a chemical element found in various ores and conspicuous for having great affinity for oxygen. The manufacture of the alloy renders obtainable in it various proportions of titanium, so that a 15 per cent. alloy means that nominally there is that amount of titanium present as against 85 per cent. of iron, but these figures are not fixed and allowance must be made for the presence of other ingredients, as carbon, aluminum, etc. The theory on which the use of ferro-titanium is advocated is very simple, hinging upon the affinity that titanium has for oxygen, or largely upon the effect of chemical reactions that occur from its addition to the molten steel, resulting in a cleansing, so that the name "scavenger" has often been applied to the alloy. There are two brands of ferro-titanium alloy available for use. The one known as the Rossi process is most frequently used, and differs principally from the other or Goldschmidt alloy in being practically free from aluminum. The latter brand contains from 4 to 6 per cent. of aluminum, which is a deoxidizing element often used in casting steel to reduce piping and blow holes. The amount of titanium alloy to be used is a matter of some argument, but in short it may be said that enough should be added to thoroughly saturate the molten metal with titanium. Theoretically, then, a trace of titanium in the finished steel may be regarded as proof that enough has been added to the molten steel to effect complete deoxidation. Recent practice advises the addition of one-tenth of 1 per cent. metallic titanium to either Bessemer or open-hearth steel, and while this figure may be taken as a safe minimum, there is abundant reason to think that a larger amount would be more satisfactory, especially under some conditions. The use of the alloy requires close attention to detail in the steel works, and should be attended with such supervision as will insure a strict adherence to the recognized principles and specifications governing its use. Success due to the use of titanium has resulted from a denser, more uniform and homogeneous metal, as might be expected from the nature of its duty as a scavenger. Granted that the metal is clarified by using titanium, the possibility of increasing the carbon content without a material loss of ductility occurs, so that of late many tons of rails have been made containing more carbon than formerly whose wearing qualities are regarded as greatly increased, and with no loss of shock-resisting qualities. Recommendations as to the carbon content as well as to the other usual elements had best be left to the individual case until more definite information has been obtained. When used under proper metallurgical conditions, titanium alloy increases the wearing qualities of rails, sufficient evidence having been produced as a result of careful measurement to justify such conviction. Whether the increased wearing quality is economically profitable to the purchaser, is a different question, depending upon the first cost of the rails, and experience with grooved girder and high T-rails for street and interurban uses, has not been sufficient to make accurate figures obtainable.

Manganese steel is a high-carbon open-hearth steel containing from 12 to 15 per cent. of manganese. Steel having such a proportion of manganese present, when quenched in water from a red heat becomes exceedingly hard and tough, but remains sufficiently ductile to resist impact. The manufacture of rails of such composition has attained considerable headway in the last few years, and it is now possible to produce any section if ordered in fair quantity. The process is quite simple, involving principally the addition of a large amount of ferro-manganese to the open-hearth metal. The treatment of the ingots in the soaking pits must be attended with great care, and finally after rolling and sawing to length, the rails must be immediately immersed in a tank of water. Naturally the long lengths become very crooked when thus cooling, so that a greater amount of cold straightening often becomes necessary. A very tough and ductile steel results, the most objectionable feature of which is the impossibility of sawing or drilling it, and therefore, careful ordering to length and punching of all holes is necessary. While the price of manganese steel rails quite precludes their common adoption for straight track, still for curves and in special or hard service track the benefits derived are such as to warrant their careful consideration.

Nickel-chrome Steel. Some large tonnages of nickel-chrome steel rails were rolled for steam roads several years ago, in which the nickel and chromium were additions to the steel of the open-hearth furnace, and have given splendid wearing results, although it is true that the rate of breakages have been high. Since that time, however, there has come into common use a large supply of iron ore, known as Cuban ore, containing nickel and chromium, rendering unnecessary any addition of these elements to the molten steel in the open-hearth furnace or converter. The use of this Cuban ore at some of the Eastern mills, has made the alloy steel available at no increase of price, and its composition running close to 1½ per cent. of nickel and one-half of 1 per cent. of chromium seems to add very desirable qualities to rail steel with a furnace addition of 3½ per cent. of nickel. Several thousand tons of this Mayari steel, as it is called, by both Bessemer and open-hearth process, have been laid in steam road track since its first offerings in 1910, but as yet the results as to its wearing qualities and breakages are still largely unavailable. Many electric railway companies have also used this steel for girder rails and the indications point to a cheap, hard, tough and ductile steel, which is much needed for rails.

High Silicon Steel. It may be well here to mention the possibilities in using an increased amount of silicon in common open-hearth steel for rails. Steel with as high as four-tenths of 1 per cent. of silicon, or double the high limit used in this country, is reported to have given excellent wearing results on English roads.

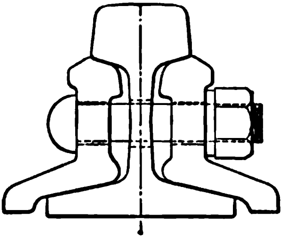


FIG. 59.—Angle bar splice.

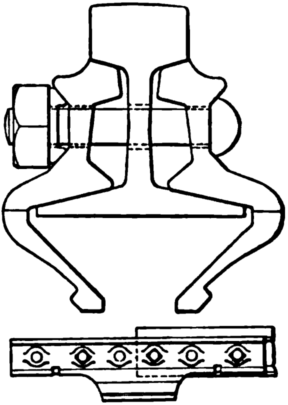


FIG. 60.—100 per cent. type joint.

Rail Joints. The common angle bar splice, Fig. 59, comes in contact with the rail along the fishing surfaces under the rail head and on the rail base. By tightening the track bolts the bars are wedged in so that shear and bending moment due to wheel loads will be transmitted across the joint giving somewhat the effect of a continuous rail. To increase the strength and stiffness, the lower flanges may be widened opposite the joint and extended down below the rail base as in the "100 per cent." type, Fig. 60, the Bonzano, Duquesne, etc. In other forms a plate is placed under the joint as an extension of the lower flange of one of the angle bars, or as a separate plate locked to the lower flanges of both bars. Figs. 61 to 66, inclusive, illustrate the special forms of joints known as the Webber, Continuous, Wolhaupter, and Atlas.

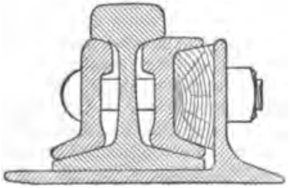


FIG. 61.—Webber rail joint.

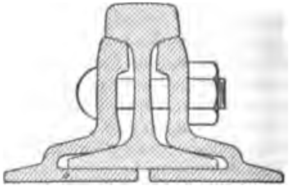


FIG. 62.—Continuous rail joint.

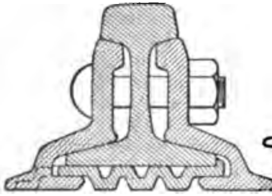


FIG. 63.—Wolhaupter rail joint.

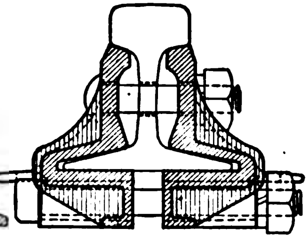


FIG. 64.—Atlas rail joint—section A-A

A number of rail joints were tested at the Watertown Arsenal under the direction of the Committee on Rail of the Am. Ry. Eng. Assn. and the results published in Bulletin 123, 1910. The span was 30 in. Two joints of a kind were tested, one with a center load of 32,000 lb. on the base, the other with an equal load on the head. The rails were then inverted and the load increased to failure or to the capacity of the testing machine. Below are given the data for the strongest and stiffest joint tested for the 100-lb. rail and for the strongest and stiffest angle bar joint for the 100-lb. and for the 80-lb. rail.

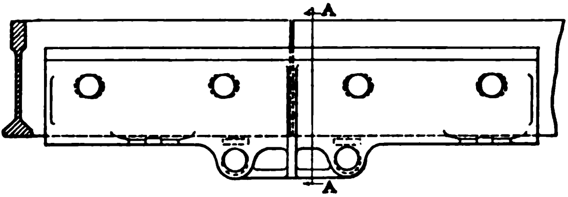


FIG. 65.—Atlas rail joint—suspended type.

	Rail			Joint		
	100-lb.		80-lb.			
	a	*b*	*c*	*a*	*b*	*c*
Area full section	9.92	10.02	7.84	13.6	6.74	6.74
Moment inertia	43.80	49.00	27.78	47.2	9.36	9.33
Section modulus, normal	14.85	15.69	10.58	15.0	4.39	4.36
Section modulus, inverted	15.64	17.00	11.11	12.24	5.14	5.12
Elastic limit, normal	119,000	125,000	85,000	72,500	56,000	55,500
Elastic limit, inverted	125,000	136,000	89,000	41,000	......	......
Max. deflection, normal	0.013	0.012	0.020	0.048	0.065	0.093
Max. deflection, inverted	0.013	0.012	0.020	0.050	0.052	0.082
Ultimate, normal	......	......	......	117,500	95,500	88,000
Ultimate, inverted	......	......	......	87,500	......	......

The 100-lb. rail, *a*, was an American Society section, the 100-lb. *b*, and the 80-lb., *c*, Dudley New York Central sections. The section modulus normal is for the head and the inverted for the base of the rail. The elastic limit and the maximum deflection are inserted from computation for comparison with the joints, with an assumed elastic limit of 60,000 lb. and a modulus of elasticity of 30,000,000 lb. It may be noted that the joints compare more favorably with the rail in section modulus than in stiffness.

The bolt holes for the splice bars and the notches for the spikes to prevent rail creeping are usually punched, and this is one of the reasons why soft steel, about 0.1 per cent. carbon, is common, but one of the pairs of bars tested contained 0.63 per cent. carbon. The length varies from about 2 ft. with 4 bolts to 3 ft. with 6 bolts, although a length of 3½ ft. has been used. The short bar is used with a suspended joint midway between two ties, the bar reaching from tie to tie. The long bar is used with a three-tie joint, the ends resting on the outer ties with the joint on the center one. The suspended joint is advocated as doing away with pounding action due to a solid support under the rail and it is required for the splice bars which extend below the rail base at the joint; the three-tie joint is advocated as giving better support for the joint (which is the first part of the rail to go down under traffic) than the two-tie support and it is used on a number of the heavy traffic trunk lines. With long bars a little wear of the fishing surfaces or looseness of the bolts has less effect in allowing angular motion, a consideration often overlooked. The track bolts are usually ¾ to ⅞ in. with round heads and elliptical section under the heads to prevent turning in the elongated holes of the splice bars. Various methods are used to prevent the nuts from rattling loose, among the most effective being the spring washer and the Harvey grip thread. The holes in the rails are drilled large enough to allow for temperature changes, the bolts acting only in tension to hold the fishing surfaces in contact with sufficient force to transmit bending moment.

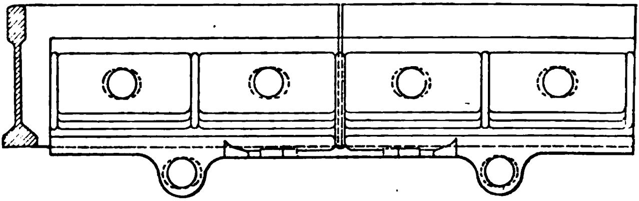


FIG. 66.—Atlas rail joint—supported type.

Rail joints may be laid opposite or alternate. The former is common in the West and in Europe. It is advocated on the ground that since the tendency of the track is toward low joints, if they are put opposite no side lurch is given and the train is easier on track and passengers. The motion, however, is unpleasant and it is hard on draft rigging and on track, the blow if both sides go down being heavier than for only one. On curves alternate joints hold alinement much better as there is a solid rail opposite each joint to prevent the track from kinking due to springing the track somewhat to fit the curvature. Again, it is more expensive on curves due to having to cut and redrill each inner rail, rather than let the inner joints run ahead until a rail 1 ft. or more shorter than the standard length can be used. Specifications provide for the acceptance of about 10 per cent. of the rails of lengths shorter than the standard by whole feet down to about 25 ft. because the cropping of the top of the ingot may prevent the remaining portion from cutting into full rail lengths.

If a concealed type of rail bond is to be used, care must be taken in the design of the rail joint that sufficient space is allowed for the bond, even after wear has taken place on the joint.

The Am. El. Ry. Eng. Assn. recommends joints for the 7- and 9-in. girder rails as shown by Figs. 53 and 54. The Committee on Way Matters, 1910, states that failures due to poor design of plate may be attributed largely to insufficient fishing surface or insufficiency of metal in the web, either of which faults may cause a line contact, or nearly so, at the fishing surfaces, thereby materially decreasing the life of the joint; the former is defective in that the contact surface approximates a line, and the latter in that the plate will bend or buckle under the load applied by drawing up the bolts, thus giving a line contact between plate and rail. An inspection of the rails and joint plates shown in the catalogs of manufacturers will furnish many examples of rail lacking in fishing surfaces, and of plates which do not avail themselves to the full extent of the limited surfaces presented. The life of this style joint will be materially increased, at small additional cost to the completed track structure, when a plate is designed of such strength and stiffness that it cannot be bent under any load applied when tightening the bolts, particularly when supplied with channel contact surfaces of such width as the head of the rail will permit. The customary lengths are 26 in. for a 6-bolt joint on 7-in. rail and 32 to 36 in. for 12-bolt joint on 9-in. rail.

Welded Joints. By the use of welded joints a continuous rail, which fulfills the three required elements of a perfect joint, is obtained, and if a permanent weld could be made, thus eliminating the joint, the life of the rail at the joint would be equal to that of the rail at any other point. The early attempts to weld rails were made by means of electricity. Later the cast weld was introduced and became very popular, and after another period of time had elapsed an improved electric weld was placed on the market, and it has divided honors with the cast weld. The latest development in the cast weld line is the thermit weld, which is essentially a modification of the general principles of cast welding. The principles of the above-mentioned joints are such that if they are perfectly installed the necessary elements desired will be had.

Cast Weld. In certain cities cast welding has been very successful, while in others the results have been unsatisfactory. The variation in the finished joint results in widely different conclusions as to the usefulness of this type of joint. Investigation, however, shows that a fair percentage of the failures may be attributed, first, to the section of the rail welded and its chemical composition; second, to an improperly designed mold and the consequent distribution of the metal; and, third to indifferent workmanship individual joints. Two of the most ordinary types of failure are to be noted. First, that known as "slip," resulting from the failure of cast metal to amalgamate with that of the rail section. This can be largely overcome by care in the selection of the metal entering into the casting, by the operators assuring themselves that the metal is poured at a proper heat, and by cleaning and sand-blasting that portion of the rail ends which it is expected will be amalgamated. Second, is the apparent injury done to the rail head by reason of the application of hot metal, which results either in the distortion of the surface or in the changing of the physical characteristics of the metal itself. The distortion can be eliminated by the use of clamps and by subsequent grinding, so that a true wearing surface may be had, and the change of the physical characteristics, due to the sudden application of heat, may be considerably diminished by the placing of a large piece of metal on the rail head to rapidly conduct the heat away, by pouring the molten metal so that the top of the cast metal may be as far below the rail head as is consistent with the strength of the joint, and lastly, by the use of water jacket.

Electric Weld. Failures of this type of welding occur through the fracturing of the rail, which takes place usually at the end of the welded bar. Several instances have been noted where the bars themselves have been fractured at the joint. This method of welding depends principally upon two items for a successful joint, first, the insertion of the "dutchmen" between the rail ends, in such a manner that the pieces inserted cannot work loose, and, second, the accurate grinding of the finished joint, together with the removal of a slight hump that occurs in welding certain sections. The electric weld develops in a degree the weakness that is shown by the cast weld, which has been designated as "slip." This weakness is occasioned by the partial failure of the central weld, and results in the independent motion of the abutting rail ends. This fault is serious, but the work may be so prosecuted that its occurrence is negligible. The report of the Board of Supervising Engineers, Chicago Traction, for 1910, states that a continued improvement in the process of electric welding is reflected in the record of rail joint failures for the past years. At that time nearly 62,000 joints had been welded, which number was expected to be increased to about 100,000 in the following year. The experience with electric weld rail joints in Chicago, therefore, affords an unusual opportunity to observe the durability of this type of joint construction as compared with the joint plates and bonds. The results of 4 years' experience are shown in the table on the opposite page.

The improvement shown in the results was brought about by the combined efforts in improving the workmanship of the weld and the more uniform conditions of power supply which became available as the work proceeded. By the use of a flux, a better weld was produced than without fluxing, and the strength and uniformity of the welds were thus increased by two or three times in many cases. The use of this flux began with the 1908 work. It was also found that a much tougher weld was produced by applying pressure gradually during welding and keeping the weld under compression until the metal had set. As a number of failures had occurred through the bar section, the size of the joint bars was increased, but owing to the excessive power required for a satisfactory weld, this size was later reduced, the dimensions at present being 1$\frac{1}{16}$ by 3$\frac{1}{2}$ in.

Summary Record of Electric Welded Rail Joints in Chicago by Yearly Groups

	Year joints originally welded			
	1907	1908	1909	1910
1907:				
Welds	8,281.00			
Breaks	417.00			
Per cent	5.04			
1908:				
Welds	8,297.00	18,371.00		
Breaks	119.00	297.00		
Per cent	1.43	1.62		
Total to 1909:				
Welds	8,297.00	18,371.00		
Breaks	536.00	297.00		
Per cent	6.46	1.62		
1909:				
Welds	8,299.00	18,380.00	21,716.00	
Breaks	92.00	91.00	104.00	
Per cent	1.11	0.50	0.48	
Total to 1910:				
Welds	8,299.00	18,380.00	21,716.00	
Breaks	628.00	388.00	104.00	
Per cent	7.57	2.11	0.48	
1910:				
Welds	8,320.00	18,413.00	21,734.00	13,233.00
Breaks	82.00	113.00	213.00	35.00
Per cent	0.99	0.61	0.98	0.26
Total to 1911:				
Welds	8,320.00	18,413.00	21,734.00	13,233.00
Breaks	710.00	501.00	317.00	35.00
Per cent	8.53	2.72	1.46	0.26

Thermit Weld. This form of cast weld has the advantage that the apparatus required is small, inexpensive and easily transportable, so that it is especially convenient for small jobs and repair work. G. E. Pellissier (Elec. Ry. Jour., 1910) states that a gang of four men made 10 complete joints in 9 hours in a busy street at Holyoke, Mass., and that under more favorable conditions they should make 15 joints in the same time. The Electric Railway Journal (1911) reports breakages of but 1 per cent. or less on the "principal railways in Germany." The process depends upon the chemical reaction between aluminum and iron oxide, which, when mixed in the proper proportion and ignited, react to form liquid steel and slag at a temperature of approximately 5400 deg. F. This reaction takes place in a small portable crucible, placed directly over the rail ends, which have been covered by a mold, into which the melted steel is tapped, the high temperature resulting in a weld of the rail ends and thermit steel. The composition of the thermit steel may be regulated to conform to the characteristics of the steel of the rail. In the earlier thermit welding practice, a space ¾ in. was left between the rail ends, which was filled with the thermit steel. This method required preliminary analyses of the rail steel to determine the amount of alloy which was necessary in the thermit steel to give a uniform wearing quality in the head of the rail across the joint. In Europe, where low-carbon steel rail is generally used, butt-welding was done by carefully filing the rail ends to parallel surfaces, holding them together with special clamping apparatus, and preheating by a small charcoal furnace immediately before the application of the mold; a second application of thermit is made to bring the rail head to welding temperature, after which the clamping apparatus forces the rail together, completing the weld. With high-carbon steel as used in American practice, difficulty was had in making the full section weld with similar composition until the adoption in 1913 of the following method: An insert of the shape as shown in Fig. 67 ¾ in. in thickness, and of the same composition as the rail (sometimes cut from the rail section) is placed between the rail ends. The thermit is poured as in the earlier method, retaining the usual weld of the base and rail, outside edge of ball and lip. The shrinkage of these welds compresses and butt-welds the rail ends and insert which have been brought to welding temperature by the preheating due to the thermit pouring. In this method, no part of the wearing surface is replaced with thermit steel, so there is no need for special alloys, and it is said that the cost of using the insert is balanced by a decrease in the amount of grinding required.

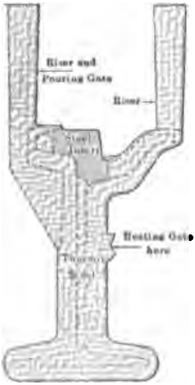


Fig. 67.—Thermit full section weld.

Clark-Thermit Joint. This joint as described by Mr. Chas. H. Clark, and as used in Buffalo and Cleveland, consists of the common joint plates with drive fit bolts and a shoe of thermit steel on the base of the rail at the joint. Rails and plates are drilled with round holes of the same size, 1/16 in. smaller in diameter than the bolts, which are standard machine bolts with square heads and hexagon nuts. The holes are reamed to fit, using special adjustable reamers with a track drilling machine. The thermit weld is made in the base of the rail after the joint has been placed and bolts drawn up tight. Mr. Clark has given the cost of 12 hole joints with 1¼-in. bolts in 140 lb. rail as $6.07 each, complete, and of 8 hole joints as $5.08 each. A modification of the Clark joint has been used in Baltimore. Special fishplates are provided, 1 in. thick and of special design to fit the contour of the head and base of rail with a minimum space between web of rail and fishplate. These are of the same high-carbon steel as the rail and are punched with ten 1 1/16-in. holes on 3-in. centers. The holes in the fishplates and rail are reamed in the field, and the fishplates riveted to the rail with 1 in. by 4¾ in. cone head rivets, after which a thermit weld is made around the base of the rail. The complete cost is given as $6.69 per joint on 103 lb. 7-in. girder rail.

Compromise joints, or the joint between ends of two dissimilar rail sections are often points of trouble, due to the fact that it is difficult to make such joint plates with good contact for both rails, except with special facilities. It is too often the case that the compromise joint is overlooked until actually needed and a rough blacksmith job is allowed to suffice only to cause trouble later. Some form of welded joint between the two rail ends is most satisfactory, and where joint welding apparatus is not available in the field, some companies weld together short pieces of the two rail sections, and use standard joint plates to connect these to the similar adjoining rails. A uniform method for designating compromise joints was approved by the Am. El. Ry. Eng. Assn. in 1912, and is shown by Fig. 68. The observer stands between rails at O, facing joints. All readings are made from left to right, as in reading a book, and as indicated by arrows on the figure. Joint X would read "one combination joint connecting Sec. A worn ¼ in.. drilled R.. with Sec. B worn ⅛ in.. drilled S."

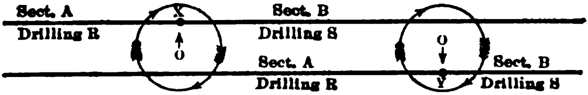


FIG. 68.—Am. El. Ry. Eng. Assn. uniform method for designating compromise joints.

Allowance for Expansion in Laying Rail. The Am. Ry. Eng. Assn. (1912) recommends that in laying new rail, standard expansion shims shall be used, that the temperature of the rail shall be taken by placing a thermometer on the rail, and that the openings between 33-ft. rails shall be as follows:

Temperature (degrees Fahr.)	Amount of opening
0– 25	¼ in.
25– 50	3/16 in.
50– 75	⅛ in.
75–100	1/16 in.
Over 100	close

The above applies, of course, to open track. The engineers on street railway lines, through experience, have concluded that the spacing of rails with open joints is unnecessary in paved streets and ascertained by practice that if the rails were butted tightly together the damage to the rail end, due to the impact of the wheels, could be minimized. This damage is in direct ratio with the width of the opening between rail ends. Therefore, in order to obtain a perfect fit of the rail ends, most rail specifications now require that, in addition to the sawing, the rails be milled and finished, and, if necessary, filed so that a true and accurate rail end may be obtained. Further, the Am. El. Ry. Eng. Assn. has, in view of the desirability of obtaining a joint with no intervening space between the abutting rail heads, recommended, in its specification for the manufacture of rails, in addition to the usual finishing of the rails at the ends, that "the rails may be undercut 1/16 of an inch. There is now in use in one of the western cities, on T-rail construction, a special form of rail end, the rail being cut to a vertical bevel in the ratio of 1 to 6. This type of cutting enables the engineers to obtain a perfect fit of the abutting rail heads and with the ordinary bolted joint has been found satisfactory. It is questionable, however, if joints of this type would be of any particular benefit if laid on heavy traffic lines.

Grinding and Compromising Joints. Many engineers believe that all joints should be ground when first installed. There is no question that a joint should not be left if there is any variation whatsoever between the running surfaces of abutting rail ends. Once the wheels have an opportunity of pounding the rail the receiving side will rapidly cup out and the track will fail. In a double track, and where the traffic is in one direction, the receiving rail, after a period of years, becomes badly cupped. If the joints are ordinary plates they may be offset or replaced with step joints so that the bottom of the cup is on a level with the top of the delivery rail. The plates are then driven tight and bolted up in place and the adjoining rails ground level. It is important that the joints be ground back in proportion to the depth of the cup, this grinding extending sometimes for a distance of 6 ft. on each side. Rail treated in this manner and having proper foundation and ties will ride like new track. Rail could have its life considerably extended if, as soon as the joints begin to pound, the plates are pulled up and the rail so ground that the abutting rail ends are a true, level surface. Such practice should be resorted to instead of neglecting the joints to such an extent that nothing is to be done except to lose the rail or apply some expensive method in reclaiming it, such as inserting short pieces of new rail.

Rail Corrugations. With the increased use of solid forms of track construction (concrete base, etc.), the advent of large cars, and the necessity of rapid rates of acceleration and braking, this form of maintenance trouble has increased greatly within the past few years. While the rail manufacturer is ready to lay the cause to modern traffic conditions, equipment and air brakes, many engineers place it with the rolling of the rail, and a satisfactory reason has not yet been offered. The corrugations must be removed by some form of grinding, either by an ordinary file or emery block set in a frame and operated by hand, or by one of the many forms of rail grinding machines. The 1910 Com. on Way Matters, Am. El. Ry. Eng. Assn., states that "the cost of removing corrugations varies from a few cents to 50 cents per foot of rail, depending on the depth of the waves," the only other remedy being to renew the rails. The grinding should be done as promptly as possible after the corrugations manifest themselves, as once started the trouble rapidly grows worse.

Cost of Grinding Rail Corrugations and Joints. Mr. C. L. Crabbs gives the following cost data covering 1 year's work on track of the Brooklyn Rapid Transit Company. The average cost per foot of grinding 21,725 lin. ft. of corrugation of an average depth of 0.01 in. was: Labor $0.112; material, $0.0227; total, $0.1347. During the same period 1418 joints and dishes of a depth approximating 0.05 in. were ground, the average cost per joint being: Labor, $0.8322; material, $0.193; total, $1.0252. This work was done with a reciprocating grinder, but Mr. Crabbs states that his experience with considerable grinding of joints with wheel machines shows very nearly the same costs.

Measurement of Rail Wear. For obvious reasons ordinary calipers are not suitable for measuring rails to ascertain either lateral and vertical wear, or even the vertical wear over the whole width of the head. Various instruments and devices have been contrived for this purpose. One idea that has been put into service is to apply molds to the sides of the rail and take a plaster-of-Paris cast, from which precise measurements can be obtained in various ways. The instrument shown in Fig. 69, consisting of a clamp *B* and a curved, tapering scale *S*, was designed by Mr. Stephen W. Baldwin, of New York City, and described in Camp's "Notes on Track." The clamp is 3/4 in. thick and is applied to the head of the rail by means of a thumb-screw *e* and stud *d* in 3/16-in. holes drilled into the rail at points where it is desired to take measurements. As the splice bars do not interfere, these holes may be drilled as near the end of the rail as is desired. Presumably each rail would be measured at the middle and near the ends. The center line, *b c*, between the opposite holes is the base line for all measurements, and as this is fixed and not affected by wear (the hole in the gage side should be drilled deep enough to place its pointed end beyond the reach of wear from the wheel flanges) the clamp, when adjusted, will always occupy the same position. To prevent corrosion in the holes they may be filled with wax after each time the instrument is used. The measurements taken between the working faces of the rail and the reference heads on the clamp (No. 1, No. 2. . . No. 7) are thus accurate records for comparing the size of the rail head at different times. The purpose of curving the tapering scale is to prevent bridging depressions in the rail surface. This scale is tapered and graduated to measure the open space between the clamp and the rail within 1/100 of an inch.

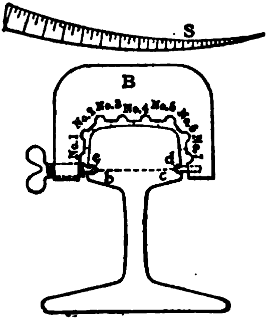


FIG. 69.—Instruments for measurement of rail wear.

Track Laying. Camp, Track, estimates that where the ties are hauled ahead by trains, 56 laborers, 3 foremen and 11 teams with drivers should lay a mile of track in 10 hours under average conditions without hurrying. The force would be distributed about as follows:

4 men loading ties
10 teams hauling ties
6 men placing ties
8 men unloading and placing rails
2 head strappers
4 back strappers
12 spikers
6 nippers
1 spike distributer
1 bolt distributer and shim collector
1 water boy
1 team on rail car
3 foremen

Total, 56 not including foremen.

Where the ties are run out on rail cars and carried ahead, one man carrying a tie as may be done with soft wood ties, 8 men are added and 9 teams subtracted from the force as given above. This is for skeleton track which should be surfaced by taking materials from the edges of the roadbed before trains are allowed to pass. Frequently it is ballasted with earth and used for speeds up to 25 or 30 miles an hour during the period of thin traffic. If other ballast material is to be used it is brought on in ballast cars and dumped or dumped and spread. The track is then jacked up, alined and tamped to surface, but new track will settle unevenly and it will take some time to get it in smooth riding condition. With track-laying machines, the rails (with angle bars attached) and the ties are brought forward from the supply cars of the construction train to the front car or machine by power, the ties are carried over the upper chords of a cantilever truss projecting a rail length in advance of the car and delivered when they can be placed without disturbing the rail men. Each rail is carried forward and lowered so that it can be easily guided to position a little in front of the splice bars of the rail in place and then pushed back by hand and partially spiked, or in some cases held by bridle bars and spiked after the train has passed ahead. Some are self propelling, others have power for handling the material only and require a locomotive for the train. The older machines are described and illustrated in Camp's Track and one of the later ones in which air is used in handling the rail from car to track, in Engineering News, 1907. In the latter case the machine was used in track laying on an interurban line starting from Tacoma, Washington, and it is stated that from 2 to 2½ miles per day could be laid with the following force: 1 foreman, 4 men to operate the machine and feed ties and rails to the conveyor, 6 men to distribute and space ties, 4 strappers, 8 spikers, 4 nippers and 1 spike peddler. An itemized cost account of laying track on the Frisco Line in Louisiana with a Harris machine is given in the Engineering-Contracting, 1910. Part of the supplies were brought 35 miles by the night crew which did some switching during the noon hour when the day crew was off. About 6000 ft. of full tied, bolted and spiked track were laid per day at a total cost of about $200 per mile, the contract price being $275. This included the switch work. It is claimed that an improvement in the bridle rods could be made which would increase the output by 1000 ft. per day or reduce the cost to $166 per mile for skeleton track.

Track Bolts. The following table shows the average num- of track bolts per keg of 200 lb.

	Square nuts							Hexagon nuts						
Diam., length, in.	½ in.	9/16 in.	⅝ in.	¾ in.	⅞ in.	1 in.	1⅛ in.	½ in.	9/16 in.	⅝ in.	¾ in.	⅞ in.	1 in.	1⅛ in.
2	770	568	441	...	...	...	...	790	611	458	...	...	...	...
2¼	730	540	420	...	...	...	...	750	580	436	...	...	...	...
2½	694	515	402	290	...	...	...	712	551	417	302	...	...	...
2¾	662	493	384	277	...	...	...	678	525	398	289	...	...	...
3	633	472	369	265	194	...	...	647	502	382	276	201	...	...
3¼	606	453	355	254	186	...	...	619	480	366	264	193	...	...
3½	581	435	341	244	179	...	...	593	460	352	254	185	...	...
3¾	558	418	329	235	173	130	95	570	442	339	243	178	136	99
4	...	...	...	227	166	125	92	...	...	...	234	171	132	96
4¼	...	...	...	219	160	121	90	...	...	...	226	165	127	93
4½	...	...	...	211	155	117	87	...	...	...	218	160	123	90
4¾	...	...	...	...	...	114	84	...	...	...	...	...	119	87
5	...	...	...	...	...	110	82	...	...	...	...	...	115	84
Weight of 1000 nuts, pounds	112	146	218	245	374	525	747	93	122	182	216	316	462	685

Track Spikes. The following table shows the number of track spikes per keg of 200 lb., also the number of kegs per mile with ties 2 ft. between centers.

Size, in.	No. in keg of 200 lb.	No. of kegs per mile
5½ × 9/16	375	29½
5 × 9/16	400	26
5 × ½	450	23½
4½ × ½	530	20
4 × ½	600	17¾
4½ × 7/16	680	15½
4 × 7/16	720	14¾
3½ × 7/16	900	11
4 × ⅜	1000	10½
3½ × ⅜	1190	9
3 × ⅜	1240	8½
2½ × ⅜	1342	7⅞

Approximate Value of Grade Determined by the Use of Tape Line. Fig. 70 (by Mr. G. M. Eaton, Elec. Journal, 1911) shows a method of finding an approximate value of a grade by use of a tape line. The tape is reefed through the end ring or eye, and a pin is stuck through the tape at a point beyond the 12-ft. mark such that when the pin just clears the ring the 12-ft. mark will lie in the center plane of the ring. The tape is creased at the 4-ft. and 9-ft. marks and is fastened to the reel in such a way that the latter may be used as a plumb bob. If possible, the ballast is scooped out to receive the reel hanging freely below the rail, as at *D*. The tape is tied to the rail at *A*, the 4-ft. mark, and is suspended by a string or wire at *B* with the portion *AB* drawn straight. The portion of the tape from the ring to *A* is drawn straight and the suspension of *B* and *C* are adjusted so that suspended tape and pin clear the ring. The number of per cent. grade is then approximately equal to $x/2$ in which x is measured in inches. That is, every half inch between the 12-ft. mark and the surface of the rail at *G* indicates approximately 1 per cent. of track grade.

Measurement of Grade by Accelerometer. If a train is standing or moving at a constant speed on a grade, an approximate value of the grade may be obtained by an accelerometer (see Accelerometer, page 176), located on the train. The accelerometer may be graduated to read the number of per cent. grade directly. If on the improvised accelerometer (see Fig. 45, page 176) the thread be attached at a point 5¼ in. from the upper end and the upper end bent until the plumb thread again cuts the 3-in. point, each ⅛ in. of deflection will indicate a p proximately 1 per cent. of grade. Due to the fact that the surface on which the accelerometer rests may not be parallel to the plane of the track, the zero adjustment of the accelerometer should be made while the car on which the accelerometer is located stands on a level track or track of known grade.

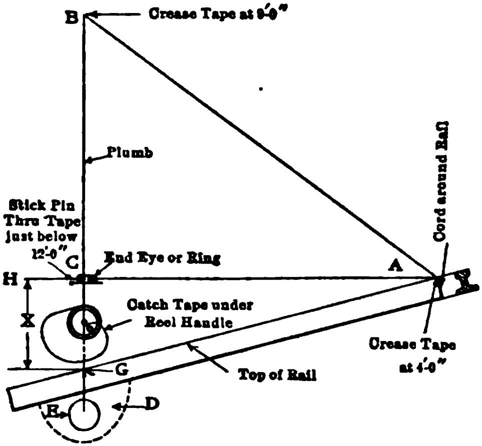


FIG. 70.—Method of finding approximate value of grade by use of tape line.

Notes on Track Curves. In American practice a curve is designated by the number of degrees of angular measure subtended at the center of the circle by a chord of 100 ft. (Fig. 71). A 1-deg. curve is a curve of such a radius that a chord of 100 ft. subtends a central angle of 1 deg., while an n-deg. curve has a radius such that a chord of 100 ft. subtends a central angle of n deg. The radius of a 1-deg. curve is 5730 ft. and the radius of an n-deg. curve is $\frac{5730}{n}$ ft. The maximum allowable curvature on new construction of trunk line steam railroads now seldom exceeds 3 deg. In street railway work, where curves of small radius are necessary, the curves are often designated by the radius instead of the degree of curve.

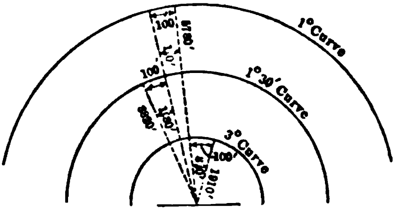


FIG. 71.—Designation of track curves.

Super-elevation of Outer Rail on Curves. On curves the outer rail is elevated sufficiently to neutralize the centrifugal force of

TABLE OF SUPER-ELEVATION FOR CURVES

Degree of curve	Speed in miles per hour						
	10	20	30	40	50	60	80
	Super-elevation of outer rail in inches						
1	....	¼	¾	1¼	1¾	2½	4½
2	¼	½	1¼	2¼	3½	5	....
3	¼	¾	2	3½	5¼	7½	....
4	½	1	2½	4½	7	....	....
5	½	1½	3	5¾	8¾	....	....
6	½	1¾	3¾	6¾	....	....	....
7	½	2	4½	7¾	....	....	....
8	½	2¼	5	9	....	....	....
9	½	2½	5¾	....	....	....	....
10	¾	2¾	6¼	....	....	....	....
11	¾	3	7	....	....	....	....
12	1	3¼	7½	....	....	....	....
13	1	3½	8	....	....	....	....
14	1	4	9	....	....	....	....
15	1¼	4¾	....	....	....	....	....

the train, which varies with the degree of curvature and the speed. The above table (Elec. Jour., 1908) gives the super-elevation for

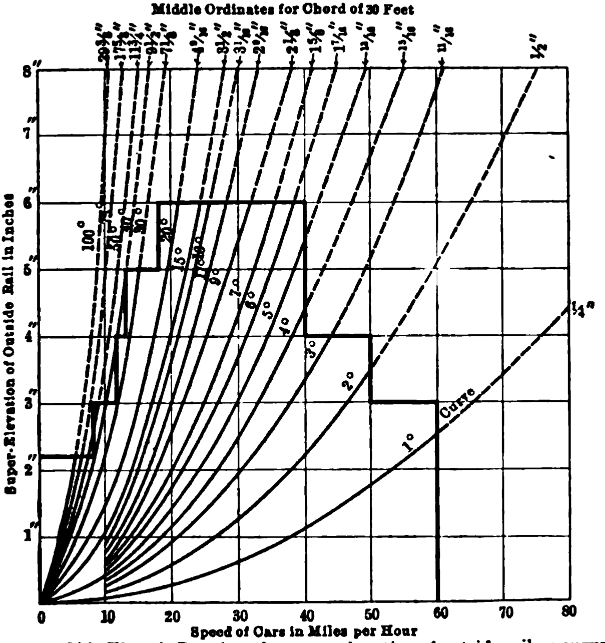


FIG. 72.—Ohio Electric Ry. chart for super-elevation of outside rail on curves.

different speeds and curvature. It is not considered good practice to elevate any curve more than 7½ in.

Fig. 72 shows a chart of the super-elevation of outside rail on curves as used by the Ohio Electric Railway Company. The chart bears the notation that the speed of cars and elevation of outside rails should be limited to figures of the chart shown inside the heavy lines. Thus, on a 4-deg. curve the track elevation should not exceed 4½ in., nor the speed of the car more than 43 miles per hour; on a 30-deg. curve the elevation should not exceed 5 in. nor the speed of the car more than 16 miles per hour.

Formula for Super-elevation. The amount of super-elevation of outside rail on curves is given by the following formula. This formula is an approximate one, but the error amounts to less than one per cent. in the case of a super-elevation of 9 in. on standard gage and is proportionately less for other super-elevations.

$$e = 0.00001165\,Gv^2n$$

where e = super-elevation of outer rail, inches
G = gage of track, inches
v = speed of train, miles per hour
n = degree of curve.

Rail Bending. In shaping a rail for use in a given curve, it is convenient to stretch a cord from end to end of the concave side of the head and bend the rail until the length of the middle ordinate (distance from center of cord to side of head) is equal to the value given in the following table for the curvature and rail length in hand. The middle ordinate for any other length of rail or degree of curvature within the limits of the table may be found by proportion.

MIDDLE ORDINATES FOR CURVING RAILS

Degree of curve	Length of rail						
	33 ft.	30 ft.	28 ft.	26 ft.	24 ft.	22 ft.	20 ft.
	in.	in.	in.	in.	in.	in.	in.
1	5/16	1/4	3/16	3/16	3/16	1/8	1/8
2	1/2	1/2	7/16	3/8	5/16	1/4	3/16
3	13/16	11/16	5/8	9/16	7/16	3/8	5/16
4	1 1/8	15/16	13/16	11/16	5/8	1/2	7/16
5	1 7/16	1 3/16	1 1/16	7/8	3/4	5/8	9/16
6	1 11/16	1 7/16	1 1/4	1 1/16	7/8	3/4	5/8
7	1 15/16	1 5/8	1 7/16	1 1/4	1 1/16	7/8	3/4
8	2 1/4	1 7/8	1 5/8	1 7/16	1 3/16	1	7/8
9	2 1/2	2 1/8	1 7/8	1 5/8	1 3/8	1 1/8	15/16
10	2 13/16	2 3/8	2 1/16	1 3/4	1 1/2	1 1/4	1 1/16
11	3 1/8	2 5/8	2 1/4	1 15/16	1 11/16	1 3/8	1 1/8
12	3 3/8	2 13/16	2 1/2	2 1/8	1 13/16	1 9/16	1 1/4
13	3 5/8	3 1/16	2 11/16	2 5/16	1 15/16	1 5/8	1 3/8
14	3 15/16	3 5/16	2 7/8	2 1/2	2 1/8	1 3/4	1 1/2
15	4 1/4	3 9/16	3 1/16	2 11/16	2 1/4	1 15/16	1 9/16
16	4 1/2	3 3/4	3 1/4	2 13/16	2 3/8	2 1/16	1 11/16
17	4 13/16	4	3 1/2	3	2 9/16	2 3/16	1 3/4
18	5 1/8	4 3/16	3 11/16	3 3/16	2 11/16	2 5/16	1 7/8
19	5 3/8	4 7/16	3 7/8	3 3/8	2 7/8	2 7/16	2
20	5 5/8	4 11/16	4 1/8	3 9/16	3	2 9/16	2 1/8

Finding Degree of Curve. It is sometimes necessary to find the degree of a curve on a completed track; this can be done by the use of a tape, by the following method: Some convenient point on the outer rail as *C* (Fig. 73) is selected. From the gage side of the outer rail at *C*, sight along the gage side of the inner rail on the line *CB*. The point *A*, where the line *CB* produced cuts the gage side of the outer rail again, is thus determined, and the distance *AC* is measured. The length *AC* is now compared with the values given in the table and the corresponding degrees of curve in the table will be the value sought. The values given in the table for *AC* are the long chords corresponding to a constant middle ordinate (equal to the gage of the track which, in this case, is 4 ft. 8.5 in.). The distance measured may vary several feet from that found in the table due to the inaccuracy of the alinement of the track, but since curves are nearly always made in even degrees, except in special cases where local conditions make it necessary, the degree of curve can almost always be determined by the above method in a very short time.

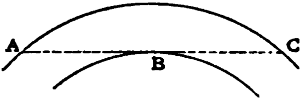


FIG. 73.—Finding degree of curve.

TABLE OF CHORD LENGTHS FOR OUTER RAIL CORRESPONDING TO MIDDLE ORDINATE OF 4 ft. 8½ in.

Deg. of curve	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°
Length of *AC* in ft.	463	328	268	232	208	190	176	164	155	147	140	134	129	124	120

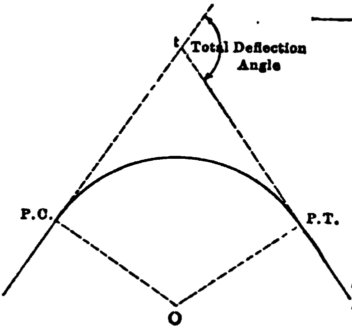


FIG. 74.—Curve to connect tangents.

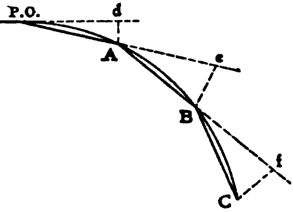


FIG. 75.—Laying out curve.

Degree of Curve to Connect Two Tangents. (See Fig. 74.) The radius of a circular curve required to connect two tangents may be found by dividing the *apex distance* (*P.C.t* in Fig. 74) by the tangent of one-half the total deflection angle. Dividing 5730 by this radius gives the degree of the curve. These rules may be expressed as follows:

$$\text{radius of curve} = \frac{\text{apex distance}}{\text{tan. } \tfrac{1}{2} \text{ total deflection angle}}$$

$$\text{degree of curve} = \frac{5730 \times \text{tan. } \tfrac{1}{2} \text{ total deflection angle}}{\text{apex distance}}$$

Laying Out a Circular Curve by Chord Deflection Distance. (See Fig. 75, also Chord Deflection Distance, below.) Assuming a chord length (100 ft. is generally used), lay off *P.C.d* on the tangent produced through *P.C.*, such that

$$P.C.d = \sqrt{(\text{chord length})^2 - (\tfrac{1}{2} \text{ chord deflection distance})^2}.$$

Locate *A* at the extremity of the first chord so that *dA* perpendicular to *P.C.d* is equal to one-half the chord deflection. Produce *P.C.A* to *e* so that *Ae* is equal to the chord length. Locate *B* so that *AB* is equal to the chord length and *eB* is equal to the chord deflection. Produce *AB* to *f* so that *Bf* is equal to the chord length. Locate *C* so that *BC* is equal to the chord length and *fC* is equal to the chord deflection.

NOTE: Results sufficiently accurate for many purposes may be obtained by taking the distance *P.C.d* equal to the chord length instead of taking it equal to

$$\sqrt{(\text{chord length})^2 - (\tfrac{1}{2} \text{ chord deflection distance})^2}$$

Chord Deflection Distance.

$$(\text{chord deflection distance}) = \frac{(\text{length of chord})^2}{(\text{radius of curve})}.$$

$$= \frac{(\text{degree of curve}) \times (\text{length of chord})^2}{5730}$$

TABLE OF CHORD DEFLECTION DISTANCES FOR 100-FT. CHORD

Degree of curve	Radius, feet	Chord deflection, feet	Degree of curve	Radius, feet	Chord deflection, feet
1	5730.0	1.745	21	274.4	36.44
2	2864.9	3.490	22	262.0	38.17
3	1910.1	5.235	23	250.8	39.87
4	1432.7	6.980	24	240.5	41.58
5	1146.3	8.724	25	231.0	43.28
6	955.4	10.47	26	222.3	44.98
7	819.0	12.21	27	214.2	46.68
8	716.8	13.95	28	206.7	48.38
9	637.3	15.68	29	199.7	50.07
10	573.7	17.43	30	193.2	51.76
11	521.7	19.17	31	187.1	53.45
12	478.3	20.91	32	181.4	55.13
13	441.7	22.64	33	176.0	56.82
14	410.3	24.37	34	171.0	58.47
15	383.1	26.11	35	166.3	60.14
16	359.3	27.83	36	161.8	61.80
17	338.3	29.56	37	157.6	63.46
18	319.6	31.29	38	153.6	65.11
19	302.9	33.01	39	149.8	66.76
20	287.9	34.73	40	146.2	68.40

The table on page 72 gives chord deflection distances for 100-ft. chord and even degrees of curve. Values of chord deflection for other curvatures within the limits of the table may be obtained from the table by proportion.

Easement Curves. Where the track passes from tangent to curve, the direction and super-elevation change suddenly. To avoid the shock and lurch of the train, due to an instant change in the relative position of cars, trucks, etc., an easement is made from tangent to curve. This easement allows the train to take the path of a spiral, *i.e.*, the degree of curve increases at regular intervals from tangent to curve until the maximum degree of curvature, or that of the simple curve, is reached. Where it is possible, the length of this spiral (in feet) is usually made fifty times the degree of curve which is being approached. The corresponding easement in elevation covers the entire length of the spiral, being zero at the beginning and increasing to the maximum super-elevation, for the simple curve, at the end of the spiral. The following notes on easement curves are from a compilation by E. R. Cary of Rensselaer Polytechnic Institute:

$L = \frac{S^3D}{1000\,r}$ where L is length of easement curve in feet, S is speed in miles per hour, D, degree of curvature and r is rate of elevating outer rail in inches per second of train speed. r may vary from 1 to 2 in. per second. Nearest multiple of adopted chord should be used for L. Distance of beginning of spiral from vertex of curve is: $Ts = Tc + d + p$ tan. ½ I; where Tc is tan. dist. of circ. curve with central angle of I, d is approximately ½L and $p = \frac{L^2}{24R}$, R is radius of curvature of circular curve.

Deflections from tangent through *P.S.* (point of spiral) are as follows:

Change of curvature per chord	Deflection for chords of 10 ft. each									
	1	2	3	4	5	6	7	8	9	10
¼	0°00¼'	0°01'	0°02¼'	0°04'	0°06¼'	0°09'	0°12¼'	0°16'	0°20¼'	0°25'
⅜	0°00⅜'	0°01½'	0°03⅜'	0°06'	0°09⅜'	0°13½'	0°18⅜'	0°24'	0°30⅜'	0°37½'
½	0°00½'	0°02'	0°04½'	0°08'	0°12½'	0°18'	0°24½'	0°32'	0°40½'	0°50'
⅝	0°00⅝'	0°02½'	0°05⅝'	0°10'	0°15⅝'	0°22½'	0°30⅝'	0°40'	0°50⅝'	1°02½'
¾	0°00¾'	0°03'	0°06¾'	0°12'	0°18¾'	0°27'	0°36¾'	0°48'	1°00¾'	1°15'
⅞	0°00⅞'	0°03½'	0°07⅞'	0°14'	0°21⅞'	0°31½'	0°42⅞'	0°56'	1°10⅞'	1°27½'
1	0°01'	0°04'	0°09'	0°16'	0°25'	0°36'	0°49'	1°04'	1°21'	1°40'
1¼	0°01¼'	0°05'	0°11¼'	0°20'	0°31¼'	0°45'	1°01¼'	1°20'	1°41¼'	2°05'
1½	0°01½'	0°06'	0°13½'	0°24'	0°37½'	0°54'	1°13½'	1°36'	2°01½'	2°30'
1¾	0°01¾'	0°07'	0°15¾'	0°28'	0°43¾'	1°03'	1°25¾'	1°52'	2°21¾'	2°55'
2	0°02'	0°08'	0°18'	0°32'	0°50'	1°12'	1°38'	2°08'	2°42'	3°20'

For other chords and other changes curvature per chord: Multiply tabular amount, for a change of 1 deg. per chord length, by the given change of curvature per chord and multiply the product by given chord ÷ 10. For fractional chords multiply deflection found for first chord by square of fractions which represent distances of points from beginning of spiral expressed in chords.

Laying Out Easement for Moderate Speeds. The following method of laying out an easement curve is from Trautwine's "Field Practice of Laying Out Circular Curves for Railroads." The process of laying out the curve is simple and the easement is sufficiently long for moderate speeds and curvatures. Let *xn*, Fig. 76, be part of the curve; and *xs* its tangent. Divide the chord deflection distance (see Chord Deflection Distance) by 10. The quotient will be *cx*. Set every stake of the entire curve inward this distance, *cx*, so that the curve shall be removed to *ca*. The radius of the curve is thus shortened by the length *cx*; but this is negligible. From *x* measure on the tangent 100 ft. to *s*; and from *c* measure 50 ft. to the curve at *o*. After stretching a cord from *s* to *o*, lay off the eleven equidistant ordinates, if for rail laying; or only the middle one (6), or it and the two quarter-way ones (3 and 9), if for grading. (Since *xs* is always 100 ft., and *co* 50 ft., the distance apart of these eleven ordinates will always be nearly 12.5 ft.) The ordinates themselves in feet are found for any curve by multiplying *cx* by the following multipliers:

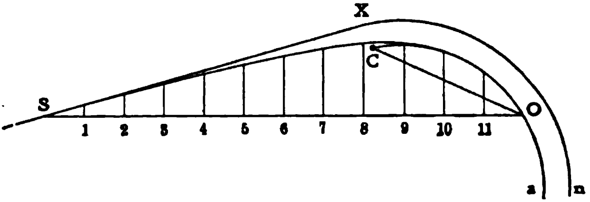


FIG. 76.—Laying out easement.

Ord.	Mult.	Ord.	Mult.	Ord.	Mult.	Ord.	Mult.
1	0.180	4	0.645	7	0.975	10	0.715
2	0.355	5	0.775	8	0.990	11	0.430
3	0.505	6	0.890	9	0.905		

Gage and Flangeway on Curves. The following method of determining the minimum flangeway required is from a report of the Committee on Way Matters of the Am. El. Ry. Eng. Assn., 1909.

Having a fixed rail groove, it is desired to know if that groove will properly serve under given conditions, and if not, how to alter it to meet them. Without discussing the question of wear on wheels or rails, let us find the minimum groove in which a given wheel flange will run, on the assumption that the equipment is geometrically perfect. In a car traversing a curve, the longitudinal axis of the car truck is normal to the radius of curvature of the track drawn to the mid-point of the truck, the wheels being held rigidly parallel to the axis. The portions of the wheel flanges which determine the size and shape of the minimum groove are the portions below the shaded sections shown in Fig. 77. The shaded areas are sections of the wheels on a level with the wheel-tread. If we project these portions of the flanges upon a radial plane, we obtain the contours of the minimum grooves, as shown at *AB*. To obtain these projections (see *ABC*, Fig. 78), pass a series of planes perpendicular to the axis of the truck. They will cut lines from the surface of the flange. Project these lines by means of track arcs upon the radial plane *AB* (shown rotated about line *AB*, as an axis, into the plane of the paper). The outline curve *FCH*, tangent to all of these projections, is the contour of the required minimum groove. The gage-line of a grooved rail or of a groove is customarily taken as the intersection of a horizontal plane through the tread-line with the head side of the groove produced, the rounded corner being ignored. On this basis, the position of such a gage-line for the minimum groove as compared with a gage-line as determined by the standard gage is determined as follows:

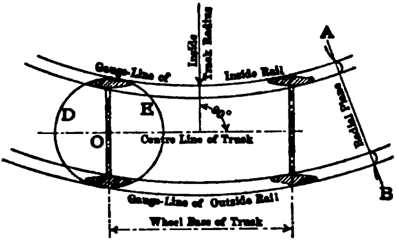


FIG. 77.—Flangeway on curves.

If in Fig. 77, with the mid-point *O* of the axle as center, we describe the circle *D–E*, of diameter equal to standard gage and draw track arcs tangent to *D–E*, one on each side and produce them to *A–B* (Fig. 78), we determine the position of the standard gage-line. Only one such determination—at *m–n*—is shown in Fig. 78. For wheels set to a gage ¼ in. less than standard gage and with the wheel gage-line taken at a point on the fillet of the flange ¼ in. below the level of the tread, it is found that the standard gage-line and the minimum groove gage-line coincide for all flanges used at the present time.

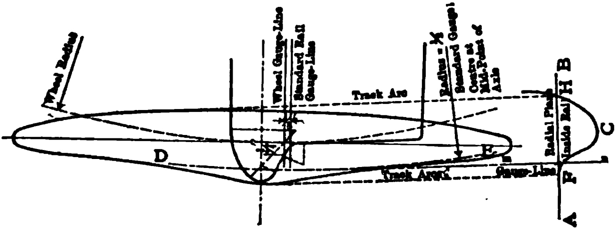


FIG. 78.—Flangeway on curves.

The Am. El. Ry. Eng. Assn. recommends the following rules for determining gage and flangeway on curves: Condition: Wheel gage is assumed to be A.E.R.E.A. standard, namely, 4 ft. 8¼ in., taken between fillets of flanges, ¼ in. below treads; track gage, 4 ft. 8½ in.

Rule 1. For A.E.R.E.A. standard wheel flanges and one wheel base use standard track gage and determine the minimum flangeways required by graphical plotting of groove, cross-section of wheel flanges, wheel base and radius of curve, as described above allowing ⅛ in. extra width in outer flangeway for irregularities in wheel setting and special work.

Rule 2. If various types of wheel flanges or various lengths of wheel bases are operated, determine, by graphical plotting, the inner flangeways required for both the maximum and minimum conditions. Use inner flangeway to suit maximum conditions and widen gage by the difference between the maximum and minimum width of flangeways as above determined. Make outer flangeway ⅛ in. wider than minimum outer flangeway for maximum conditions plus the amount of the widening of the gage.

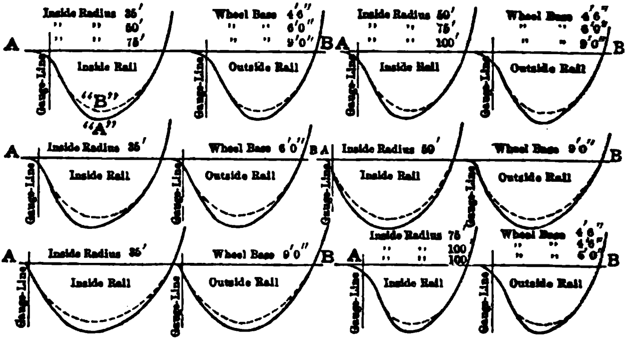


Fig. 79.—Minimum grooves for Am. El. Ry. Eng. Assn. flanges A and B.

Rule 3. Rolled guard rails having too narrow flangeways should be planed on gage side of inner rail and on guard side of outer rail to obtain required width.

Rule 4. If inside flangeway be too wide, increase the gage the difference between the width of the flangeway and the narrowest groove required. Make the width of outside flangeway equal to that required by the maximum conditions of inside radius, wheel flanges and wheel bases increased by the difference in widths of the narrowest and widest inside grooves as required by the inside radius, wheel flanges and wheel bases and also by $\frac{1}{16}$ in., thus maintaining approximately ⅛ in. allowance for irregularities in wheel settings and special work.

Rule 5. In expressing specification for gages and flangeways measure gage on a plane ¼ in. below the head of rail at fillet, except that when steam railroad wheels are to be used give distance on plane ⅝ in. below the head of rail, making special notation thereof.

Rule 6. Measure flangeways horizontally from gage-line opposite head of rail. Give vertical slope of guard if rails are to be modified.

Mr. Victor Angerer in a paper before the Keystone Railway

Club (1913) said that theoretically for track laid to true gage every combination of radius of curve and wheel base of truck, with a given wheel flange, calls for a specific width of groove to make the inside of the flange of the inside wheel bear against the guard and keep the flange of the outside wheel from grinding against the gage-line and possibly mounting it. It is manifestly impracticable to provide guard rails with such a variety of grooves or to change the grooves of the rolled rail. The usual minimum of $1\frac{9}{16}$ in. is wide enough to pass the A.E.R.E.A. standard flanges on a 6-ft. wheel base down to about 45-ft. radius, and the maximum width of $1\frac{11}{16}$ in. down to about 35-ft. radius. On curves of larger radius the excess width should be compensated for by a corresponding widening of the gage. If the groove in the rolled rail is too narrow for given conditions, it must be widened by planing on the head side of the inside rail, to preserve the full thickness of the guard, and on the guard side of the outside rail to preserve the full head. Unusual wheel bases such as 8 ft. or 9 ft. may require widening of the gage on some curves. This widening of gage is necessary only to bring the guard into play when the groove is too wide for some one combination of wheel and flange. In T-rail curves the guard is formed of a rolled shaped guard, or a flat steel bar, bolted to the rail. In special work and curves in high T-rail track a girder guard rail is often used. This is desirable, as it gives the solid guard in one piece with the running rail. The idea that a separate guard can be renewed when it is worn out does not work out in practice, as it is usually the case that when the guard is worn the running rail is also worn to such an extent that it will soon have to come out also. The only drawback to the girder guard rail in high T-rail track is the compromise joint ,between the two. This, however, may be properly cared for, as described elsewhere.

Hard Center and Solid Manganese Special Work. In such special work as frogs and crossings at the present prevailing prices, few lines can afford anything less durable for tracks in paved streets than "hard-center" work. In this special work the pieces are formed of rails held together by a casting into which they are partly fused or welded, or they are made of an entire steel casting. In either case a recess is left in the central part into which a hard metal plate is set and fastened in various ways. The best metal for the centers is manganese steel, although some work is still made with chrome or tool steel centers. On account of the difficulty of machining manganese steel and because heating it to some marked degree destroys its toughness and wearing quality, certain limits are placed on the methods of applying and fastening manganese steel castings as centers in the main body of the special work. One method is to use a pendent lug and key going through the lug and body, pulling the center down into the recess. Another is to use a combination of wedges applied to the edge of the center and between it and the wall of the body portion. Another method is by use of a nut and brass set screw between horizontally extending lugs on the center and corresponding recesses in the body portion; and still another is the method of simply bolting down the center by vertical bolts running through both the body and center plate. In all except the last-mentioned method, zinc or spelter is poured in between the lower side of the center and the body. In the bolted-down center zinc is also used in the same way in some cases, while in others the under surface of the center and the top surface of the recess are finished by grinding and planing, and the two pieces are bolted together without the zinc centers. Much stress has been laid on the so-called renewability feature of special work, but any mechanically jointed center that is easily detachable would, when put under repeated strains, be likely to detach itself. On the other hand, this renewability feature has been applied very little in practice, as where centers are renewed on account of wear, it is very difficult to make a good job out of the surfaces, even by a very large amount of grinding of the adjoining parts on account of the necessarily unequal wear on the two sides of the rail. A good manganese steel center should outlast the adjoining portion of the body or rails, particularly the curved portions which exist in nearly every piece of special work. The wearing out of those portions of special pieces which had been made of ordinary rail outside of the manganese steel center led to the introduction of solid manganese steel special work in which the entire frog, crossing or other piece was made in one manganese steel casting with the arms cast and ground to correspond to the shape of the adjoining rail and joined to it with the regular joint plate. The main drawback is the greater cost, but in many cases the severity of traffic will warrant the greater initial outlay.

Frogs and Crossings. In the construction of frogs and crossings of either the hard-center or solid type, the bottom of the grooves should be raised so that the wheel when crossing the intersecting groove will have a simultaneous bearing of the flange on this raised floor and on part of the tread, this flange bearing being a necessity with narrow tread wheels. If the wheel treads are wide enough to span the intersecting groove and still leave a good amount of bearing of the wheel tread on the running surface and wide enough so that when crossing a groove at right angles the blow may be distributed on a considerable area, this flange bearing is not necessary.

Switch Tongues and Mates. The above general remarks regarding the construction of frogs and crossings also apply to the mates with tongue switches. A solid manganese casting for the body portion particularly recommends itself in the tongue switch. The important factor in the switch is the tongue bearing or pivot which should be constructed to hold the heel of the tongue steady and to give the greatest possible resistance against the knocking down of the tongue at the heel end. It must also have means of taking up the wear so as not to allow the tongue to get too loose and still it must work loosely enough to permit throwing devices, like electric track switches, to move the tongue under all conditions. Special attention must be given to the tongue switch to take up wear as it occurs. The tongue is now usually reinforced by lateral flanges against the thrust of the weight of the cars. Tongue locks, which are devices in which a spring holds the tongue in one or the other position, should not be necessary in a properly constructed tongue switch if the bearings are kept as snug and tight as they should be, but are safeguards against a tongue which is too loose or which has tendencies of accidental throwing between trucks.

Special Work for Standard T-Rail. In standard T-rail for unpaved streets practically the same details of construction are followed in the various special pieces as in girder rail and high T-rail work, except that the low T-rail gives a better opportunity for the use of solid magnanese steel pieces at no marked increase in cost over hard-center work. A class of hard-center work used in connection with standard T-rail is known as insert work. In this construction the main portion of the special piece is built up of rails, and a small manganese steel casting, which corresponds in extent to the center plate of hard-center work, is bolted in between the rails. The cost of this is not much less than that of the solid manganese work, however, and the latter is therefore preferable in new work. Inserts find their best places in repair work where the lengths of the original pieces, often of ordinary bolted construction, must be adhered to and where solid manganese steel pieces may become too expensive because of additional length. Little ordinary bolted work is now used in T-rail track on public highways except in places

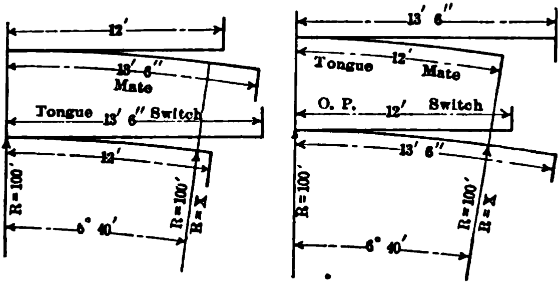
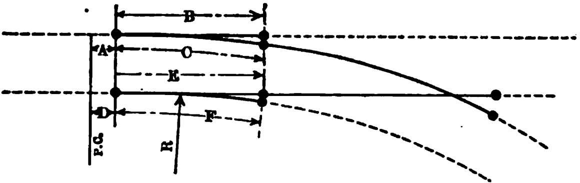


FIG. 80.—100-ft. inside radius switch pieces with broken joints.



Stated Radius	R for all tracks	A	B and C	D	E and F
50′ Lateral	47′7½″	-6″	10′0″	-6″	10′0″
75′ "	72′7½″	0″	12′0″	0″	12′0″
100′ "	97′7½″	0″	12′0″	0″	12′0″
150′ Lateral	147′7½″	12″	14′0″	12″	14′0″
200′ "	197′7½″	18″	15′0″	18″	15′0″
100′ Wye	97′7½″	-6″	10′0″	-6″	10′0″
150′ "	147′7½″	0″	12′0″	0″	12′0″
200′ "	197′7½″	0″	12′0″	0″	12′0″
350′ "	347′7½″	12″	15′0″	12″	15′0″

Standard Switches and Mates — Dimensions

FIG. 81.—Dimensions of Am. El. Ry. Eng. Assn. switches and mates.

where the traffic is unimportant or the headway infrequent, and sometimes inside of carhouses. In standard T-rail work on private rights-of-way where steam railroad practice can be followed the ordinary frogs and split switches should be used for the sake of economy. However, where traffic on such lines is very heavy, manganese steel frogs of either the solid or rail-bound type and split switches with manganese steel points should be used. If the wheels on such roads have a narrow tread, provision must be made for flange bearings in frogs and crossings, thereby distinguishing the work from the regular style of steam railroad work. In the ordinary bolted frogs and in the fixed line of spring frogs this is usually done by making the filler between the rails of steel and carrying it up to the necessary height of the groove.

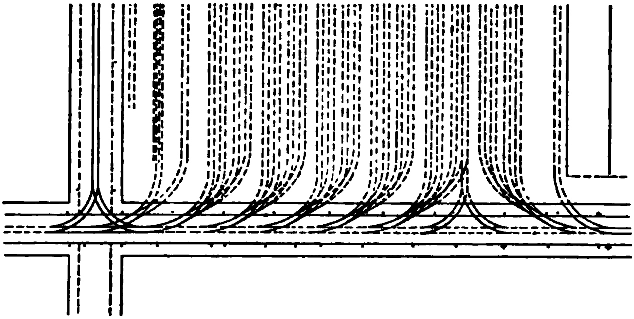
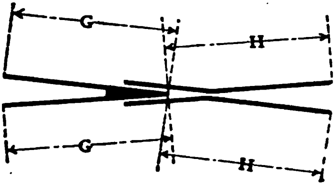


FIG. 82.—Portion of layout using 186 standard switches and mates.

Dimensions of Switch Tongues, Mates and Frogs. Fig. 80 shows 100-ft. inside radius switch pieces with joints broken, and a table (Fig. 81) gives the guiding dimensions of switches of different radii as recommended by the Am. El. Ry. Eng. Assn. It appears that a 100-ft. radius switch is satisfactory for many urban roads and its possibilities are shown in Fig. 82, which is a portion of one layout, in which, under many conditions, 186 standard switches and mates are utilized. Another table (Fig. 83) gives a list of A.E.R.E.A. recommended frogs for turnouts and cross-overs, desig-



No. of Frog	Angle	Arm Length G	Arm Length H
No. 4	14°-15′	5′-0″	4′-0″
No. 5	11°-25′	5′-6″	4′-0″
No. 6	9°-32′	6′-6″	5′-0″
No. 8	7°-9′	8′-0″	5′-6″

Lengths revised Sept. 8, 1910

FIG. 83.—Dimensions of Am. El. Ry. Eng. Assn. frogs.

nating the frogs by numbers following steam road practice, in which the frog number is the ratio of the length from the theoretical point to the heel to the pread between the gage-lines at the heel (Fig. 88). Fig. 84 shows a 100-ft. radius switch applied to make up a standard cross-over. It is interesting to note that from the records of one of the large manufacturers it is shown that over half of all the switches ordered were of 100-ft. radius, also that very few of the street railway companies favored spiral switches.

Open Track Point Switch. As shown in Fig. 86, the outer rails of the track as seen in facing the turnout are continuous, one along the main track and the other as the inner lead rail of the turnout; each is kinked slightly to protect the points of the switch rails which are placed between the continuous rails. The switch rails are bent and planed so that the gage side of the head will be straight and the other side conform to a given spread at the heel and thickness at the point without cutting away the web. The Committee on Track of the Railway Engineering Association, 1912, recommends a spread of 6¼ in. between gage-lines, a throw of 5 in. at the first rod and a thickness of ¼ in. at the point which is afterward ground to ⅛ in. and the top corner rounded. A ⅜-in. reinforcing bar is riveted to the web on each side and carried back as far as the heel connections will permit. The bottom of the switch rail is planed to

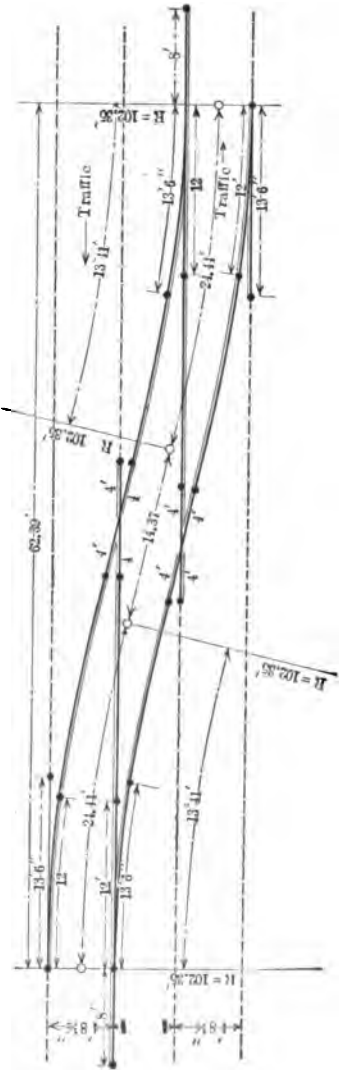
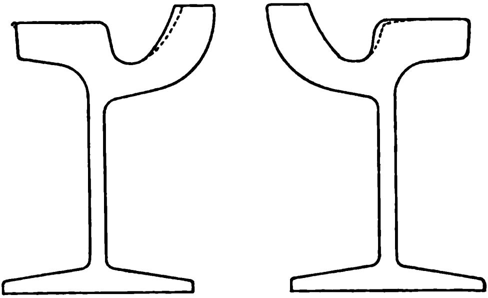


FIG. 84.—Application of 100-ft. radius switch to standard cross-over.

fit on base of stock rail where bases overlap, Fig. 87*a*. Stop blocks are used as shown, Fig. 86, to support the free portion of the switch rail from the stock rail which has a brace at each tie. The supporting plates for the two rails are planed with a step to raise the



Inside of Curve Outside of Curve

FIG. 85.—Wear on manganese steel guard rails after 700,000 car movements.

top of the switch rail ¼ in. to provide for hollow tires. The top of the switch rail is planed down to be ¼ in. lower than the stock rail and this planing runs out or rises ¾ in. in the following distances:

Length of switch rail	Length of planing
33 ft.	12 ft.
22	9
16½	7
11	5

The above lengths of switch rail are arranged for cutting from 33-ft. rails.

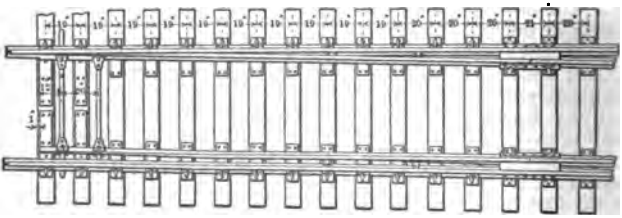


FIG. 86.—Open track point switch.

The committee claims that when the corresponding switch angle exceeds one-fourth the frog angle, the switch point presents the worst feature in the alinement and there is an economic loss both in space occupied and in cost of turnout. On this basis the committee recommends the following lengths of switch points:

16½ ft. for frogs over No. 6, and including No. 10
22 ft. for frogs over No. 10 and including No. 14
33 ft. for frogs over No. 14
11 ft. for frogs No. 6 and under when required.

Frogs Nos. 8, 11 and 16 are recommended as meeting all general requirements for yards, main track switches and junctions, with the object of eliminating other numbers and reducing the stock pile. The lengths shown in the drawings submitted are 13¼, 17¼ and 24 ft., respectively, for the three numbers. The rails are all bolted through the webs, using fillers or washers for spacers, while for the rigid frogs the rail bases are riveted to a plate.

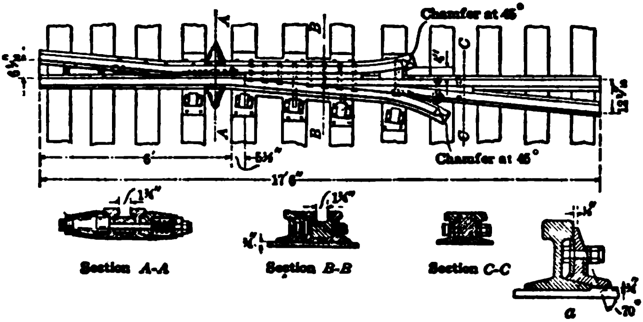
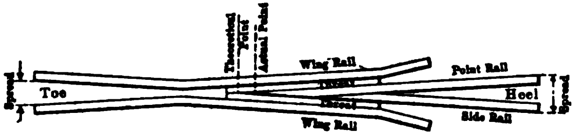


Fig. 87.—Open track spring frog (No. 11).



No. of frog	Angle		Length		Actual				Theoretical				Spread	
					Point to heel		Point to toe		Point to heel		Point to toe		Heel	Toe
	deg.	min.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	in.	in.
4	14	15	6	0	3	7	2	5	3	9	2	3	11¼	6¾
5	11	25	7	0	4	3½	2	8½	4	6	2	6	10¹³⁄₁₆	6
6	9	32	8	0	5	0	3	0	5	3	2	9	10½	5½
7	8	10	9	0	5	8½	3	3½	6	0	3	0	10⁵⁄₁₆	5⅛
8	7	10	10	0	6	2	3	10	6	6	3	6	9¾	5¼
9	6	21	11	0	6	10½	4	1½	7	3	3	9	9⅝	5
10	5	44	12	0	7	7	4	5	8	0	4	0	9⅝	4¹³⁄₁₆

Fig. 88.—Dimensions of standard rigid frog for open track.

The standard **rigid frog,** with the various dimensions, is shown by Fig. 88.

The **spring frog** is used for main line work where there is but little traffic on the side track on account of the better support of the wheel treads at the frog point. For the side track, the spring yields to the pressure of the wheel flanges and the frog acts otherwise like a rigid frog. With hollow treads the wings receive heavy blows from wheels coming in the direction to reach the heel or wings first unless the latter are chamfered to inclined planes as shown in Fig. 87. To protect the frog point and prevent derailments, a guard rail is necessary on each track with a flangeway of about 1¾ in. to guide the wheels past the frog. Where the turnout is on the outside of a curve, a guard rail is often placed in advance of the switch point to prevent the flanges from crowding and possibly getting behind the point when set for main track. Cutting the side track point about 2 ft. short allows the guard rail to reach more nearly opposite the main track point.

For the **switch ties,** if spaced about 20-in. centers, with two 7 by 10-in. by 14-ft. ties for the head block and 7 by 9-in. ties for the others, there will be required on the basis of 8 ft. length for single track about as follows:

No. 8 frog, 16½-ft. switch rail	2700 ft. B.M.
No. 11 frog, 22-ft. switch rail	3550 ft. B.M.
No. 16 frog, 33-ft. switch rail	5000 ft. B.M.

The cost of **switch stands,** including rods, lamps, etc., is about from $25 to $30, and the labor cost of laying and surfacing, $50.

Crossings. The crossing of electric railways with steam railways forms a distinct class of special work and, owing to the extreme weight of steam trains, the wear of such a crossing is hardly comparable with other electric railway special work. These crossings are sometimes built up of rail sections with or without hard center or inserts, or at times are made of solid manganese castings. The maintenance of track in good alinement and surface at grade crossings is a difficult matter in most cases, owing to the tendency of the traffic to shift the crossing out of position as well as to crush the ballast which supports it. A solid concrete base has been tried, but this was found to be too rigid, and an interesting development

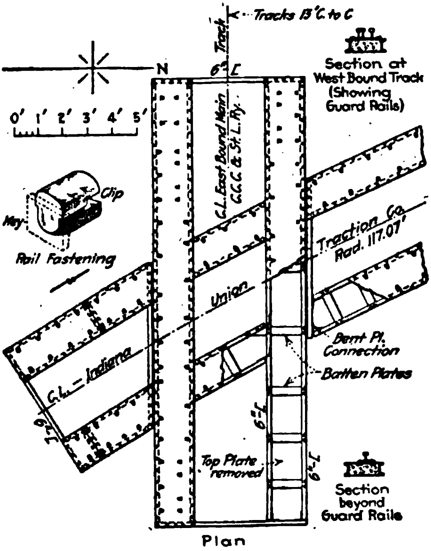


FIG. 89.—Steel substructure for grade crossing.

is the use of steel longitudinals to carry the rails at the crossing, these being connected to form a unit structure, so that the rails are maintained permanently in proper position. Such a steel substructure for the grade crossing between the Indiana Union Traction Company and the two parallel main tracks of the Cleveland, Cincinnati, Chicago & St. Louis Railroad at Muncie, Ind. is described in the Engineering News (1913) and shown in Fig. 89. This crossing carries a heavy daily traffic of electric cars and steam trains.

Each rail is carried on a longitudinal of two 6-in. channels 16 in. apart, with flanges outward, connected at top by a continuous 20 by 5/16-in. plate and at the bottom by straps or batten plates 4 by 5/16 in. and 2 ft. apart. Both ends of each piece are closed by a 6-in. transverse channel, riveted to the longitudinal channels by short angles or bent plates, thus forming a complete box. About 3 weeks before this substructure was installed, each longitudinal was filled with concrete, in which light reinforcing rods were imbedded. The rail fastenings consist of grooved clips fitted to holes in the cover plates of the longitudinals, the groove embracing the top of the rail flange and the bottom of the cover plate. When the clip is driven into position a steel key is fitted behind it, filling the hole and preventing the clip from working loose. It is stated (1915) that the crossing is in good condition and that the total maintenance cost for 2 years has been but $46.43.

Portable Cross-over. In many cases, due to reconstruction work on one side of a double track, or to enable a temporary terminal to be established on a double-track line to meet temporary traffic conditions, or for other reasons, it is desirable to install a temporary cross-over between the two tracks of the double-track line. Such a portable cross-over as used by the Detroit United Railway, is described in the Electric Railway Journal, 1911, and shown in Fig. 90. The cross-over is made of 7-in. "guaranteed" construction with run-offs at each end of 70-lb. rail. It is put together with iron spacing bars with a shoulder on each end and a drive key on the outside of the rail. By the use of the key the cross-over can be put together and taken apart in a very short time. Flanged shoes, attached to the bottom of the rails, hold the cross-over at its proper place on the track and are also used for sliding the cross-over on the track rails. As the cross-over is of such weight that it cannot be pushed by a car, it is not necessary to fasten it to the track in any manner. The cross-over while in use in Detroit has been moved from place to place on lines where cars are operated on a headway of 1 minute without delay to the regular cars. The cross-over is pulled by the regular cars on lines where these cars have a four-motor equipment. On lines which have not this equipment construction cars are sent out to shift the cross-overs when necessary. With the old type of surface cross-over it was found that the expense of moving from one location to another was $8 for labor and $4 for material and repairs to the pavement. The sliding cross-over is moved from one location to another for a total expense of $2, making a saving in each movement of $10. The total saving due to the introduction of this type of cross-over on the Detroit city lines is estimated at about $4000 per

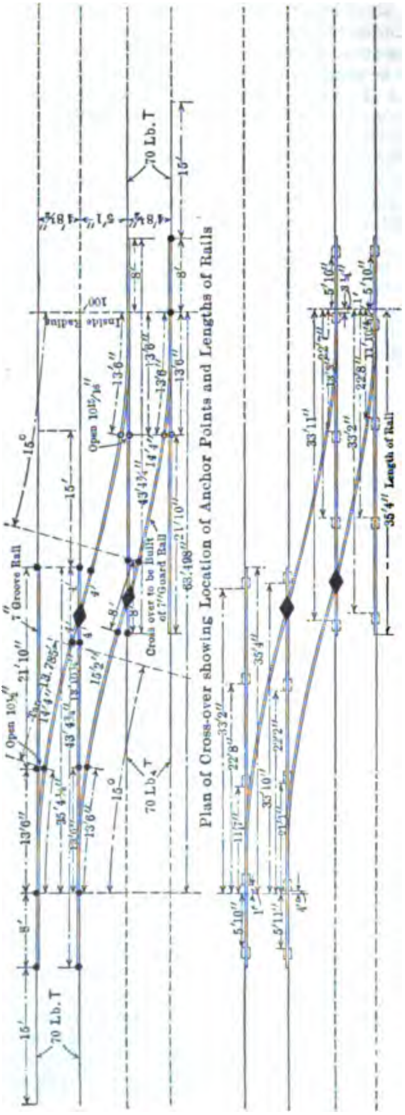

Plan of Cross-over showing Location of Anchor Points and Lengths of Rails
70 Lb. T
7" Groove Rail
Open 10¼"
Open 10¹⁵⁄₁₆"
Inside Radius
100'
15°
Cross-over to be Built of 7" Guard Rail
35'4" Length of Rail

FIG. 90.—Detroit portable cross-over.

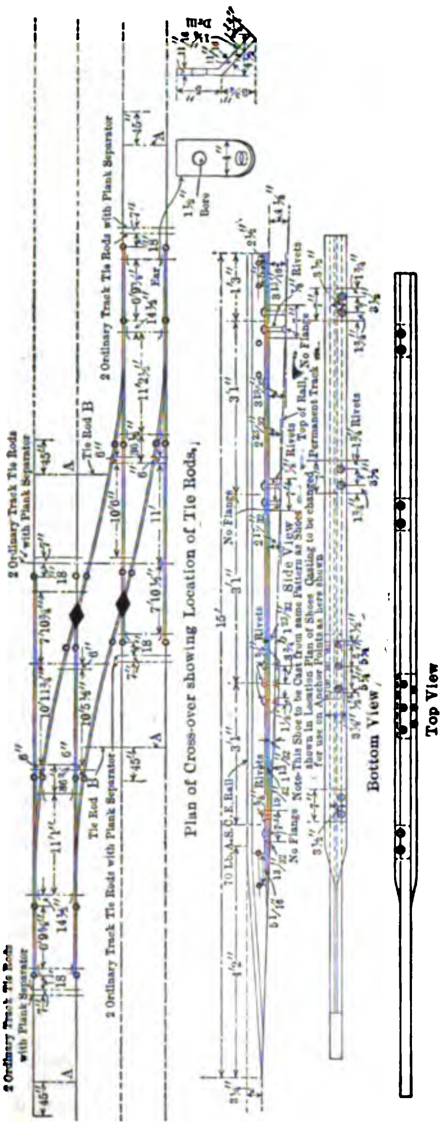

2 Ordinary Track Tie Rods with Plank Separator
Tie Rod B
2 Ordinary Track Tie Rods with Plank Separator
Tie Rod B
2 Ordinary Track Tie Rods with Plank Separator
2 Ordinary Track Tie Rods with Plank Separator
A
Plan of Cross-over showing Location of Tie Rods.
Bore
70 Lb. A.S.C.E. Rail
No Flange
Rivets
Side View
Note- This Shoe to be Cast from same Pattern as Shoe shown in Location Plan of Shoes. Casting to be changed for use on Anchor Points as here shown
Top of Rail
No Flange
Permanent Track
Rivets
Bottom View
Top View

FIG. 90.—Detroit portable cross-over.

year. The new cross-over has been found to be more reliable than the old surface form and less of a disturbance to the operation of cars. Derailments from its use are unknown.

A later type of this cross-over is built of 80-lb. A.S.C.E. rail with standard angle bar joints. The frogs are of solid manganese type and the tongue and mates of hard-center manganese construction. The cross-over is provided with rail inserts of various lengths to accommodate variations in distance between tracks.

Derailing Switches. Derailing switches may be used as additional safety devices in connection with interlocking plants at grade crossings, at the ends of side tracks and at other points where it is imperative that cars or trains do not pass a given point except under certain exact conditions. Under favorable conditions cars may be expected to start unaided on a grade of about 5/10 of 1 per cent., but wind will start cars down an easier grade, and heavy wind may start them on level track. The setting of brakes should not be depended upon to hold cars that are left alone; consequently, wherever there is likelihood that cars on side track may start from gravity or be blown or easily pushed, the only safe policy is to provide for derailing them before they can get far enough to obstruct main track. A derailing switch may consist of a single moving rail connected with a switch stand, although sometimes two moving rails will be used, as in the stub switch. The rails should be set to guide the wheels away from the main track. Switch points for derails may be made more blunt than those commonly used in turnouts, but for derails in side tracks old point rails too badly worn for main track service may be used. The throw of the switchpoint should be such that a derailed wheel may pass between the point and stock rails without spreading them apart, and at the heel of the point rail the nuts of the splice bolts should come on the gage side. In side tracks much used the derails should be connected with the main line switch or switch stand, so that the operation of closing the switch for main track opens the derail, and *vice versa*. This connection is usually made by means of throw rods and bell crank. There are also various special forms of derailing devices other than the common ones mentioned above. Wherever a derail is used on main track it is desirable to prevent, as far as possible, the ditching of derailed trains. In order to hold the wheels to the ties a long guard rail should be laid on the track about 8 in. from the opposite rail, extending from a point in advance of that where the wheels are derailed.

Catch Sidings. For stopping runaway cars or trains on heavy grades without derailing, resort is sometimes had to catch sidings. Camp gives an example of such provision as found on the Canadian Pacific road between Hector and Field, B. C., near the summit in the Rocky Mountains, where there is a 9-mile grade of 4.4 per cent. Along this grade there are spur tracks or "blind sidings" 1 mile apart, each tended by a switchman. Each spur track runs up into the mountain side several hundred feet on a very steep grade which rises in the direction in which the grade of the main track falls. Normally the switches are all set for the side-track and are not closed for main track unless called for by whistle. Hence, if a train or detached cars get beyond control and come down the grade they are diverted to a heavy up grade at the first switch, without giving any signal. As the speed at which the runaway cars are liable to enter such a siding is high the curvature of the turnout should be easy and the angle of the switch points small. Wherever it is feasible to do so, it would be well to have the switches for such sidings turn from the outside of a curve in main track. This arrangement would permit of easy curvature in the turnout, or perhaps enable the turnout to branch off at a tangent. In lieu of the up-grade arrangement the catch siding is sometimes buried in sand to the depth of a few inches over the rails. Sand tracks are more common in Europe than in this country. A cross-sectional view of a sanded catch siding in use at Dresden, Saxony, is shown in Fig. 91. The rails of the diverting track are laid gauntlet fashion, on the same ties with the main rails, and the stretch of diverting track is provided at both ends with a switch for connecting with the main line. Guard timbers or angle irons for retaining the sand are placed at both sides of each rail of the siding, which gradually dips deeper until it is covered by 2 or 3 in. of sand. The arrangement is considered very efficient for the purpose. In this particular instance the catch siding is 1640 ft., long and 1148 ft. of the same is covered with sand. In very dry weather the sand is kept damp. The braking effect of sand sidings is discussed in "Engineering" (London, England, 1897), and in the Bulletin of the International Railway Congress (1899). The Street Railway Journal (1906) gives the results of a series of tests on a catch siding as installed on the New Jersey & Hudson River Ry. & Ferry Company's line, where the catch siding is located on a 7 per cent. grade and the approach of the sand track for a distance of 1500 ft. is also a 7 per cent. grade. The catch siding is 180 ft. long. The car used in making the test was one of the company's standard closed cars, weighing 22 tons and equipped with M.C.B. trucks and 33-in. cast wheels. The results of the tests were as follows:

No. of test	Speed M.P.H. entering sand track	Depth of sand over head of rail	Distance car ran	Remarks
No. 1	14.5	2½ in.	80 ft.	Free rolling.
No. 2	19.5	2½ in.	180 ft.	Front truck left track when leaving sanded section, after slight application of air brakes.
No. 3	15.0	80 ft. of ½ in. 40 ft. of 2½ in.	120 ft.	Free rolling.
No. 4	23.0	80 ft. of 1 in. 100 ft. of 2½ in.	180 ft.	Brakes set and wheels slid on last 40 ft. of test, leaving a coating of sand ¼ in. on rail.

On this road in climbing the sides of the Palisades, the tracks take a zigzag course up the face of the cliff and ascend at an average grade

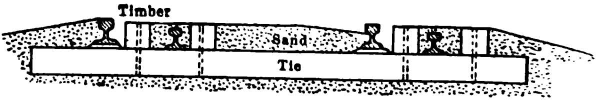


FIG. 91.—Sand track for catch siding.

of about 7 per cent. The catch sidings are installed on all the steepest grades and the switches are always left open so that it is necessary for a car to come to a dead stop at this point, and for the conductor to get off to throw the switch for the main line. An automatic tripping mechanism is used whereby the car, after opening

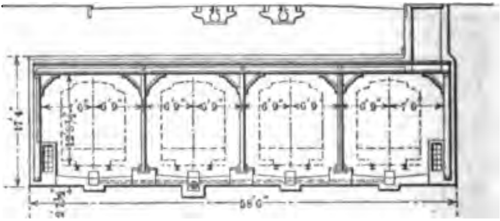


FIG. 92.—New York Rapid Transit Subway. Typical 4-track section above water.

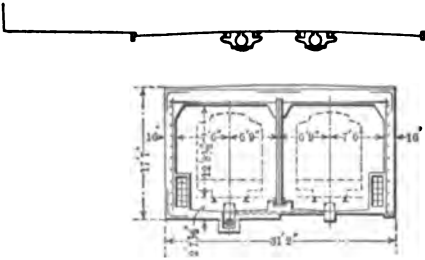


FIG. 93.—New York Rapid Transit Subway. Typical 2-track section, Lexington Ave.

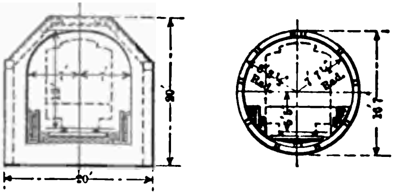


FIG. 94.—Hudson & Manhattan concrete and iron tunnels.

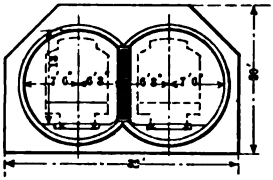


FIG. 95.—New York Rapid Transit Harlem River double tunnel.

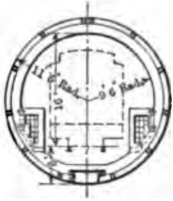


FIG. 96.—Pennsylvania R. R. North River tunnel.

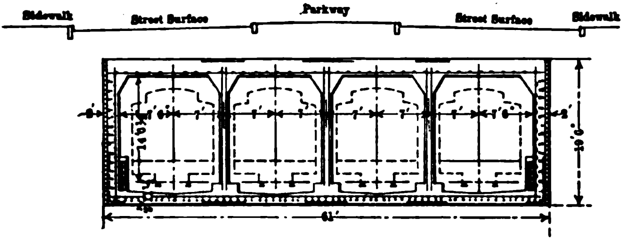


FIG. 97.—Fourth Ave. subway, Brooklyn.

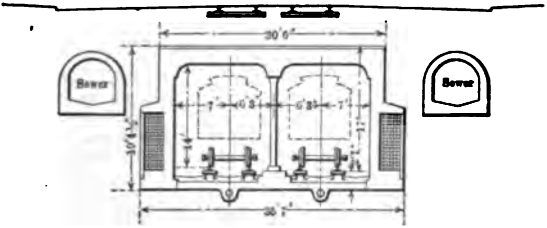


FIG. 98.—Market St. subway, Philadelphia.

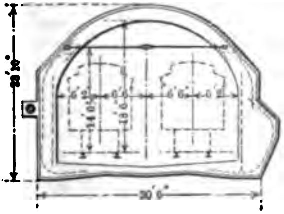


FIG. 99.—Boston subway, Washington St. tunnel.

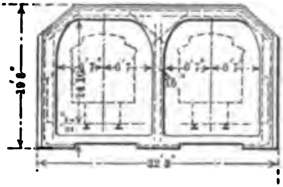


FIG. 100.—Cambridge subway, Boston.

the switch, automatically resets the switch point for the catch siding.

Electric Track Switches. In the operation of the Cheatham switch, the car is run under a trolley pan (placed a little more than a car length in front of the switch point) with current on if it is desired that the switch be set in one direction, or with current off if it is to be set in the other direction. Referring to Fig. 108, assume that the car is using current as it passes under the pan. As the trolley wheel strikes contact *E* of the pan, the current used passes through solenoid *A*, the plunger of which throws the circuit changer *F* into contact with plate *G*; as the trolley wheel proceeds, it makes contact with *C*, and current for operating the switch point passes

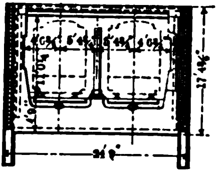


FIG. 101.—Berlin subway, Schöneberg extension.

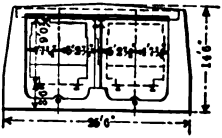


FIG. 102.—Buda-Pest subway.

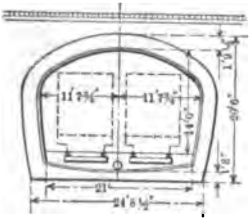


FIG. 103.—Metropolitan railway of Paris.

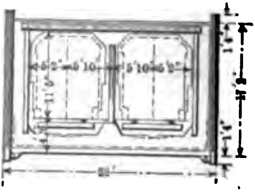


FIG. 104.—Hamburg subway in districts with ground water.

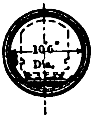


FIG. 105.

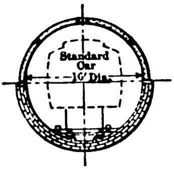


FIG. 106.

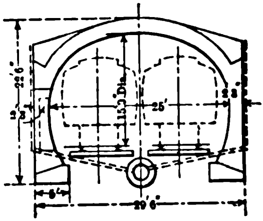


FIG. 107.

FIG. 105.—City & South London Ry.
FIG. 106.—Great Northern & City Ry., London.
FIG. 107.—Metropolitan & District Ry., of London.

from the trolley wire through *D*, solenoid *A*, *E*, trolley wheel *C*, resistance *J*, *F*, *G*, and solenoid *R*, to ground, solenoid *R* moving the switch point to the right (in this case) through switch rod *S*. To set the switch point for the other direction, the car takes no current (except lights and heater circuits) as it passes under the pan; these auxiliary circuits require insufficient current to operate solenoid *A*, the circuit changer *F* remains in contact with *H*, and current flows from trolley through *D*, *A*, *E*, *C*, *J*, *F*, *H*, solenoid *B* and solenoid *L* to ground, solenoid *L* moving the switch point to

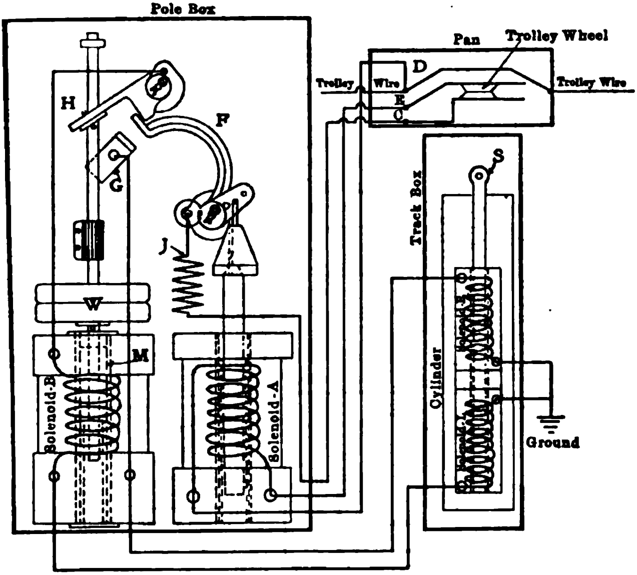


Fig. 108.—Cheatham electric track switch.

the left (in this case). As current flows through solenoid *B*, its plunger raises the weight *W* slowly against the damping effect of mercury in the cup *M*, and if current flows for an abnormal length of time, as in case of a car at a standstill with trolley wheel in pan, the tripper arm *H* is raised, allowing the circuit changer *F* to fly back and open the circuit between *F* and *H*.

The operation of the Squiers electric track switch, as shown by Fig. 109, requires the installation of two section insulators in the trolley wire. The isolated section of trolley wire, *C*, is from 4 to 10 ft. in length, and is so placed that the trolley wheel passes over it in approaching the switch. If a motorman desires to throw the switch, he uses power as his trolley wheel passes over the isolated section of trolley wire; if he wishes the switch to remain in the position in which he finds it, he coasts under this section. Referri to Fig. 109, the switch connecting rod, *S*, is shown as thrown to th right. If the power be used as a car passes over the trolley secti *C*, the path of the current is from trolley at *B*, through solenoi *E* and *D* to trolley section *C*, thence through trolley wheel to ca equipment and ground. Slide *M* is in its extreme right positio covering the opening above solenoid *E* and mechanically preventin the plunger of solenoid *E* from rising. Solenoid *D*, however, lift its plunger which carries a circuit closer between contacts *G* and *F*,

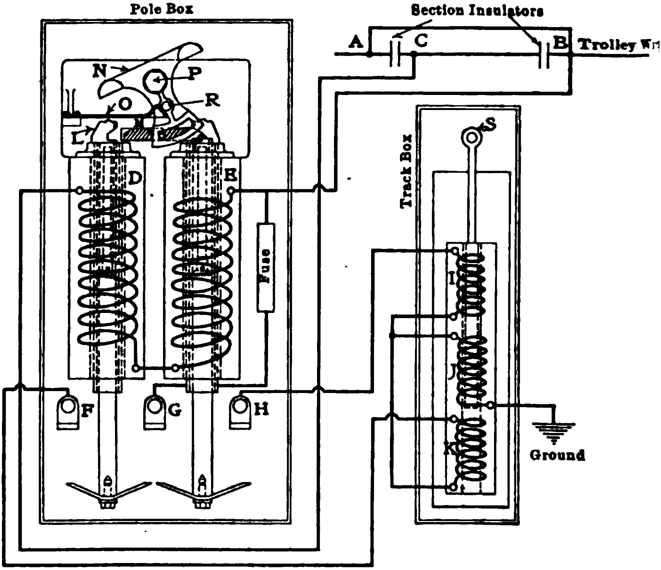


FIG. 109.—Squiers electric track switch.

so that a circuit is established from trolley at *B*, through a fuse to *G* and *F* and thence through track solenoids *K* and *J* to ground, and the track solenoid plunger with its switch connecting rod *S* is pulled to the left, throwing the switch in that direction. As the plunger of solenoid *D* rises, its brass push rod lifts the left end of rocker arm *N* around its center *P* until the slot at the bottom strikes the pin on the slide *M* and moves the slide to the left, but not far enough to uncover the opening above solenoid *E*, as the slide is stopped in its movement to the left by the brass push rod which is projecting through the opening above solenoid *D*. The rocker arm *N* has rotated far enough in a clockwise direction, however, so that the pin *R* has passed the peak of the inverted *V* at the end of spring *O*. After current has ceased to flow in the main circuit through solenoids *D* and *E*, the plunger of *D* drops, with its push rod, allowing the spring *O* to complete the movement of the rocker arm and slide *M* to the left, covering the opening over solenoid *D* and uncovering that over solenoid *E*. In the next succeeding operation of the apparatus, then, the plunger of solenoid *D* is kept down by the slide *M*, and solenoid *E* raises its plunger, completing the operating circuit from *G* to *H* and through track solenoids *I* and *J*, throwing the track switch to the right. Solenoids *D* and *E* are so designed that current for the lights, heaters and air compressor motor of one car is not sufficient to raise the plunger, so that if a car coasts under trolley section *C*, the track switch is not moved.

The American or Collins electric track switch also makes use of track solenoids which are energized directly from a line contactor which has an aluminum main frame with a bronze lever for the trolley wheel to run on. The lever is pivoted at the entering end of the contactor and the entering end of the lever is insulated both from the main frame and from the leaving half of the lever, which is connected with a contact trigger which is always alive. When a car passes under the contactor the trolley wheel leaves the trolley wire and runs on the under side of the pivoted lever which is pressed upward by the pressure of the trolley wheel, causing the contact trigger to fall on one contact piece if the car current is off and on the other if the car current is on, the selection being controlled by a solenoid which is in series between the insulated and uninsulated portions of the contact lever. A later type of the Collins switch is operated by a small motor instead of by solenoids and has an interlocking device to prevent a following car from operating the switch until the first car has passed over it.

SECTION II

BUILDINGS

While it is not possible within the limits of this volume to go into any great detail on the matter of buildings, it has been thought desirable to include some notes on the design, particularly of car houses, from typical structures and from the reports of the Am. El. Ry. Eng. Assn. committees on Car House Design (1908) and on Buildings and Structures (1911), as well as some notes on the layout of the repair shop which appeared in the Electric Railway Journal, 1912.

Layout of Tracks for Car House

Grade of Tracks. The grade of tracks in the car house should be somewhat above that of the tracks in the street to prevent the entrance of water into the house.

Convenience of Operating. In an operating car house the saving of time is of paramount importance, and the special work should be so planned that the incoming and outgoing cars will not interfere with each other, and the tracks should be constructed in the best manner. In a storage house inconvenience and loss of time may be tolerated, and here, for the sake of safety on the main line, trailing switches are preferred by many roads.

Car-house Track Layouts. Figs. 1 to 12, inclusive, illustrate special work designed to meet certain conditions. Where convenient to have it, a Y incorporated in the special work will permit the operation of cars from one end, as is necessary with cars of some designs and is convenient when operating service and other cars in tandem. This same object can be attained by a loop, which is more convenient but not always feasible, owing to a lack of room. Fig. 1 shows a track layout where the car house is built on the street line and it is desirable to introduce as few frogs and switches in the main line as possible. The three-track bay arrangement is objectionable on account of the roof span, which would require trussing. Fig. 2 shows a track layout which will permit frequent operating on one of a pair of tracks. Operating on the other track requires the use of a cross-over in the street. Fig. 3 shows a layout for an operating house which introduces a minimum amount of special work in the street. Fig. 4 shows a gauntlet track layout beside the main track to minimize frogs and switches in the main track. Fig. 5 shows a similar layout to Fig. 2 except that the operating tracks are on the right-hand side of the house. Fig. 6 shows a layout for a house on a through line operating in either direction. The Y is formed by a cross-over on the two center tracks. Fig. 7 shows a large operating house which calls for a long, narrow track approach. The Y is formed at the entrance to the street. Fig. 8 shows a track layout for a storage house which is built well back from the street. Fig. 9 shows a third track approach to a car house, a layout which requires a wide street. Fig. 10 shows a track layou where the approach to the lot is restricted at the street. Fig. 1 shows a common type of terminal layout; special work built with 4-in., 48-lb. T-rail. Inside of 3 years the mates were all renewed and within 6 years the special work was entirely worn out and

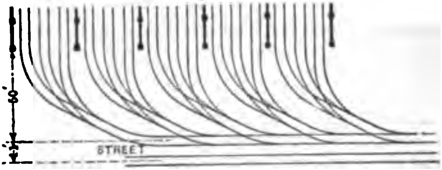


Fig. 1.

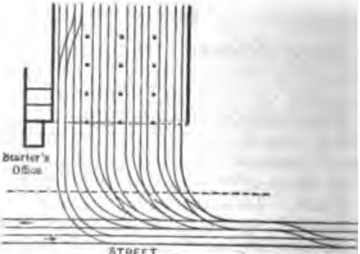


Fig. 2.

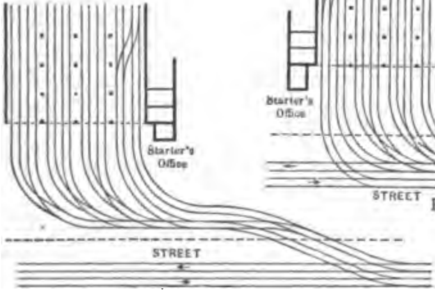


Fig. 3.

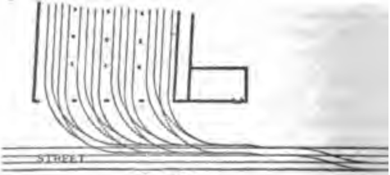


Fig. 4.

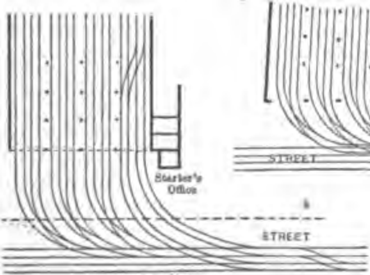


Fig. 5.

Figs. 1–5.—Car-house track layouts.

was replaced with 4¼-in. rails with hardened centers according to the layout shown in Fig. 12. The car house has a capacity of 127 cars, and there are operated from it 336 cars daily on five different lines, or one car every 90 seconds during rush hours.

The track layout of a double-end car house for single-end cars is shown in Fig. 13. This is the layout of the Luzerne car house of the Philadelphia Rapid Transit Co. The main feature of the track plan (Fig. 14) is a loop around the substation and transportation buildings. One side of this loop is a ladder track having all switch points facing the direction of car movement. Cars, therefore, which approach the terminal from either direction may easily be turned by passing around the loop, and at no time will they encounter a facing switch point except when backing into the car

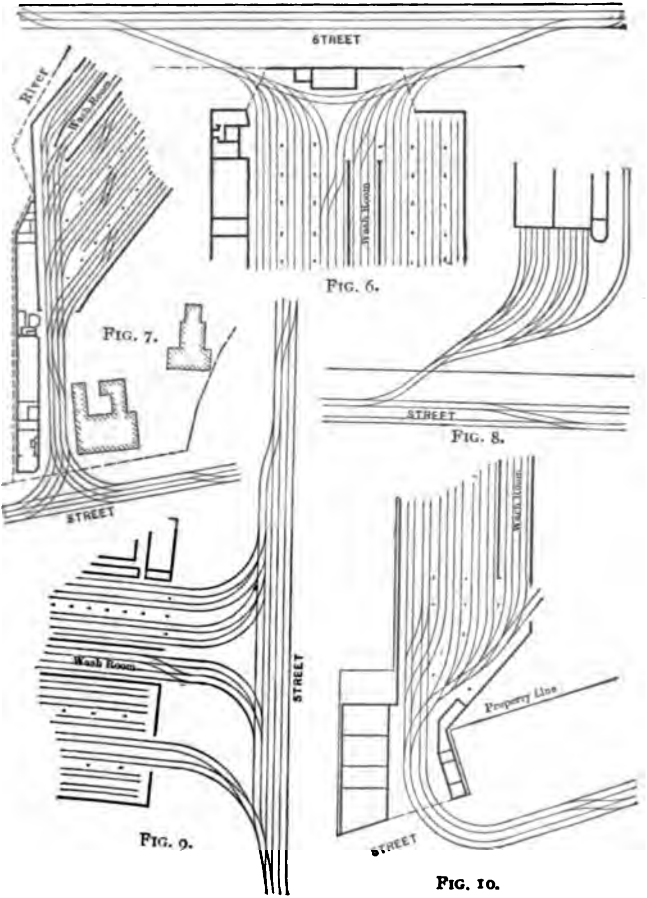


FIG. 6.

FIG. 7.

FIG. 8.

FIG. 9.

FIG. 10.

FIGS. 6–10.—Car-house track layouts.

house for a trailer or for inspection at the end of the day. This arrangement also makes it possible simultaneously to couple a half dozen trailers to as many motor cars on as many tracks without

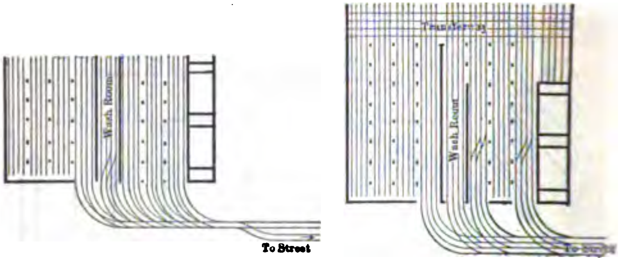


FIG. 11. FIG. 12.

FIGS. 11–12.—Car-house track layouts.

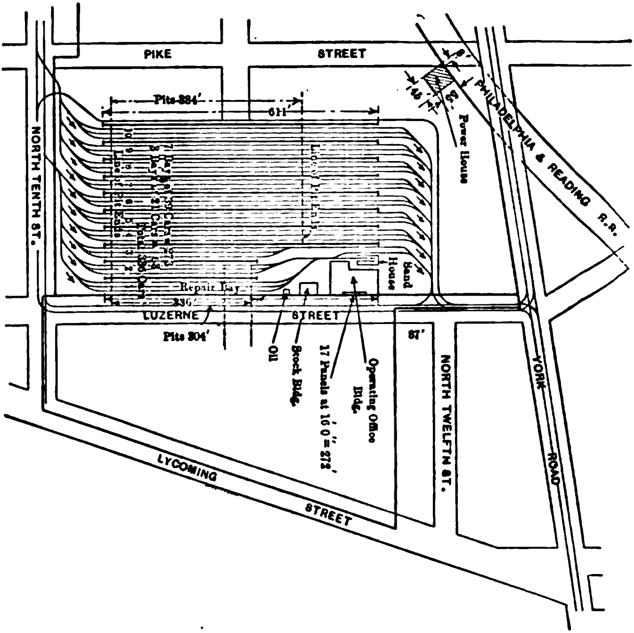


FIG. 13.—Luzerne car house, Philadelphia Rapid Transit Co.

having one crew get in the way of another. It is the intention to store many trailers here between the morning and evening rush hours, thus saving the dead mileage to their regular car houses at the ends of the several lines. This is the layout at the Forbes St. terminal of the Pittsburgh Railways. Fig. 17 shows the layout of the Harvard Ave. car yard of the Cleveland (Ohio) Railway. This layout contains many loops. A Y is formed by the necessary special work at either entrance.

Housing Car-house Special Work. In general, car-house special work requires no more protection from the weather than does special work on any other part of the track. Whether or not car-house special work, ladder track, for instance, should be covered will depend upon the possibilities of keeping the car house sufficiently warm during freezing weather. In this connection, it should be noted that ice should be melted from incoming cars in time for overhauling. An exposed ladder track will require a door for each track or group of tracks entering the car house from the ladder track, while a covered ladder track will require only one door at the entrance. For this reason, the necessary temperature will be more easily maintained with a covered ladder track. A covered ladder track requires the expense of extra wall and roof, but its trolley wire construction may be simpler and more durable than that for exposed special work.

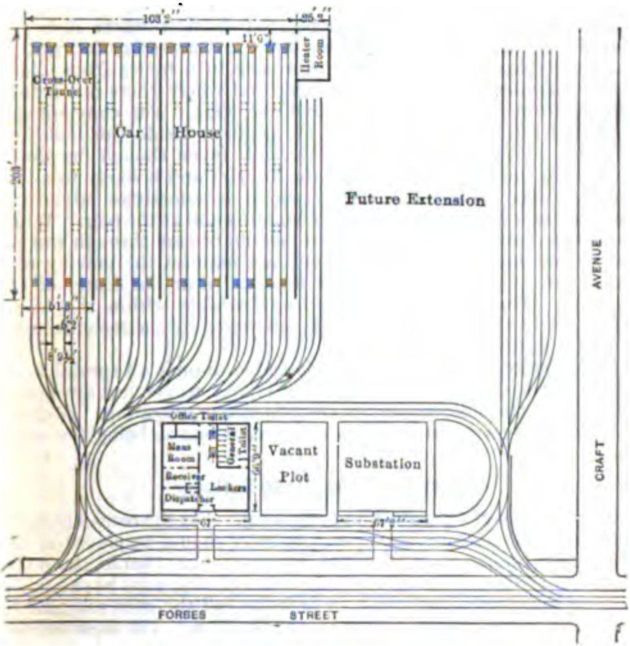


FIG. 14.—Forbes St. Terminal, Pittsburgh Rys.

Clearances. Frequent accidents have shown the necessity of establishing proper clearances between cars and between cars and posts, walls and other fixed portions of the building. The minimum clearance should be 2 ft.; on curves it is well to increase this on account of the constantly increasing size of cars.

Spacing of Tracks. Clearances also determine the minimum spacing of tracks. Eleven feet center to center is satisfactory for a storage house, with 2 ft. additional if posts occur between tracks. This spacing will also do for inspection section of pit room in an operating house, but where a great amount of work is to be done it is desirable to increase this distance.

Transfer-ways. In closely populated districts where it is not feasible to have all tracks entering ones, it is necessary to install a transfer-table. This is equally necessary in a house from which a large number of cars are operated, and where there is constant shifting from closed to open cars and *vice versa*. For convenience, it should be located centrally. Its position inside the building, however, if it passes through party walls (even though fire doors be used in the openings) adds to the fire risk and is likely to affect the insurance rates. For this reason it is sometimes advocated that the table be placed outside the building and at the rear. When so placed, however, it requires the passing of cars through the pit room when being shifted and oftentimes requires the moving of a large number of cars—more than if placed near the center of the building. The objection that a transfer-table within the house causes a loss of storage space can be answered by the recommendation of a flush transfer-table.

Cross-overs. While generally desirable to omit all special work within the house, on certain types of layout cross-overs are necessary within the building for the convenience of operation. A right-hand cross-over is preferred to a left-hand one as being the more convenient.

Design of Car-house Building

Convenience of Operation and Working. For the convenience of operation and working, the operating force should be placed at the front of the building. The starter, or whoever has charge, should be placed where he can see all incoming and outgoing cars; he should be in close touch with the lobby, in order to call the men assigned to duty, and to preserve discipline among the men. The superintendent, or any other official interested in the operation of the cars, having quarters at the car house, should be placed in an equally advantageous position. That portion to be set apart for working and repairs should be placed far enough back in the house to prevent interference from shifting cars.

Quarters Other than Operating. Besides the quarters for operating and repair forces, which are found connected with almost all car houses, some roads desire to provide quarters for such departments as machine shop, blacksmith shop, paint shop and road and line departments. If a power station or substation is to be located on the premises it is better to have it in a separate building from the car house. Some substations, however, are built as part of the car

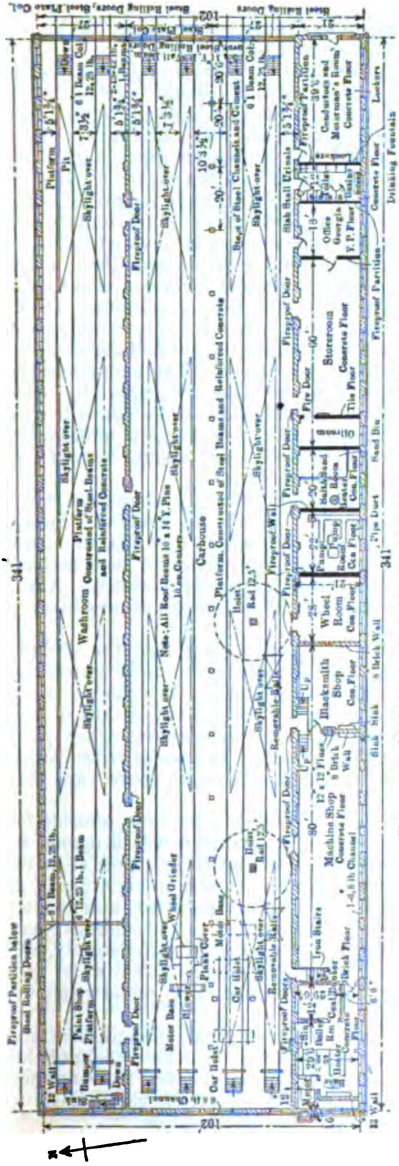


Fig. 15.—Middletown car house and shop, Connecticut Co.

house, but they are of fireproof material. It is sometimes found necessary to provide a stable under the same roof as the car house, but in such a case it should be shut off from the car house by fire walls, and the penetration of odors and ammonia to the storage portion should be prevented. Where operating houses are located away from populous centers it is often desirable for the road to provide some place (a separate building on account of fire risk) for employees to obtain meals, or interest other parties in providing accommodations of this kind. In similar locations quarters for sleeping are also desirable for men who have to be held for work on snow or night duty. These quarters may be located in the car house. Fig. 15 shows the layout of the Middletown car house and shop of the Connecticut Co. The offices and shops are arranged along one side of the building. The first room to which entrance is obtained is that for the conductors and motormen, where lockers, a drinking fountain and other conveniences are installed. Following this are the toilets, the master mechanic's office, storeroom, oil room, salt and sand room, pump room, wheel room, blacksmith shop, machine shop, coal storage and boiler room.

Fire Protection. The importance of providing fire protection should not be underrated, and at no time should it be forgotten In selecting the location for the house, proximity to buildings of inflammable material or having contents that burn easily should be avoided. Car houses should also be located where a good hydrant service is obtainable, and as near to a fire station as possible. If this is not done a private service with ample supply of water must be installed. Provision must also be made for a secondary supply of water, either in reservoirs under floor, or in elevated tanks.

Fire Prevention. No road should expose more than a certain per cent. of its rolling stock to the risk of destruction by any one fire, as the loss of cars means the loss of revenue. Divide the house by party and curtain walls where it is practicable to do so without interfering with the operation of cars or increasing the cost of the building to a prohibitive extent. The omission where possible of combustible material is recommended, especially below the grade of top of rails. Its use should be avoided on outside walls and cornice work. Sheathing partitions inside are undesirable, and floors and roof, if they are to be of wood, should be mill construction, with heavy timbers and planking.

In the construction of a car house, corners and recesses where rubbish would tend to accumulate should be avoided. Special care should be taken to avoid the accumulation of oily waste and rags. Fireproof receptacles should be provided for such material and they should be regularly and frequently emptied. Ample light and cleanliness will aid greatly in reducing the possibility of fire to a minimum.

Insurance Regulations. It is recommended that the designer familiarize himself with the regulation of the fire underwriters and adopt their suggestions as far as practicable. Insurance requirements are important factors in determining many details of construction, and a consultation with the underwriters when planning may save many expensive changes. The underwriters stipulate that no section of the house shall contain more cars than amount to the value of $200,000.

Automatic sprinklers are to be preferred as the best possible fire protection in enclosed places where the sprinklers will be opened by the heat of the fire. The very fire itself which is sought to be extinguished sets in operation the influence which extinguishes it, at the particular spot where the fire is and at no other, and entirely independent of human action. This applies to all buildings whatsoever. There should always be two sources of water supply, and any two of the following methods can be adopted: city water with adequate pressure; elevated tank; pressure tank; underwriter fire pumps.

Auxiliary Protection. Sand pails, chemical extinguishers and water pails should also be provided. Small hose lines are advisable for reaching sparks and flames in places not reached by water from the sprinklers. Inside hose reels should be placed in glazed boxes to prevent them from injury and ordinary deterioration.

Outside Protection. For open spaces, including yards, automatic sprinklers are not available, since the heat will not operate to open the sprinklers. For such places the available methods of protection are: (*a*) Universal nozzles on standpipes; (*b*) standard fire hose and nozzle; (*c*) open sprinklers set in operation by human agency.

Universal nozzles on standpipes are the best protection. There is no possibility of delay during a serious fire through the bursting of hose occasioned by kinks, or momentary excessive water pressure, or by the accidental cutting of the hose by the running of the cars over it in trying to remove them from car yards. The nozzle should not be less than 1⅛ in. or more than 1¼ in., if the water supply and pressure can be had. Since the operator cannot move such nozzles bodily to the place of the fire, the range of the nozzle should not be more than 100 ft. in order to secure the greatest degree of efficiency, which distance will necessitate as high a pressure as can be safely maintained. High water pressure is advisable for the further reason that the operator may be at a safe distance and still place water upon the fire. Intense heat may prevent the operator from placing water upon the spot desired if the water pressure

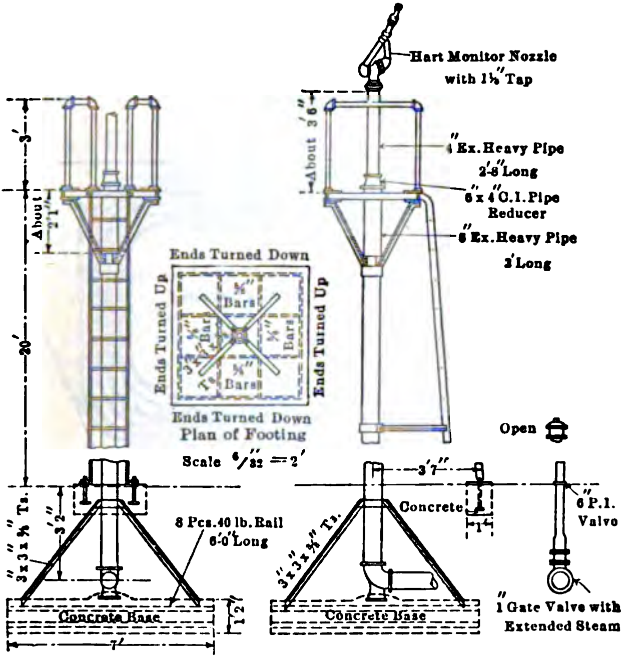


FIG. 16.—Water tower, Puget Sound Traction, Light & Power Co.

is too low. This condition applies to nozzles on hose as well The universal nozzle should be located at a height of from 10 to 1 ft. above the tops of cars. The pressure at the nozzle should be 10 lb. if possible. For this pressure the discharge for 1¼-in. and 1½-in., 1¾-in. and 2-in. nozzles will be, respectively, 466, 671, 904 and 1104 gal. per min. It is believed that the effective way to extinguish a fire, especially one which has gained much headway, is to concentrate one or more heavy streams of water upon one particular car in the yard and maintain it there until its effect is shown. This can be readily accomplished with a standpipe and universal nozzle. Pumps should be provided to supply at least two nozzles at one time. Nozzles should be located so that their range circles will overlap safely. Universal nozzles are the best protection for practical installations where cost is considered; they are certainly to be preferred over standard hose and nozzle in yards where cars are stored. Universal nozzles should be supplemented by small hose and nozzle for getting at sparks and flames not accessible to the stream of the universal nozzle, also by water pails and chemical extinguishers.

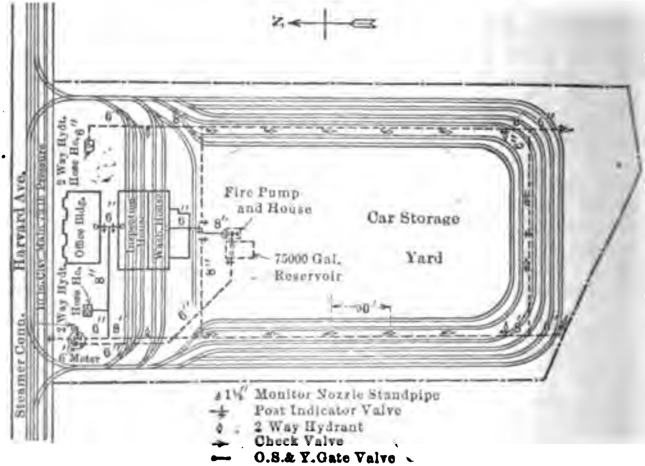


FIG. 17.—Plan for standpipes, Cleveland Rys.

Fig. 16 gives the details of such a water tower as installed in the yards of the Puget Sound Traction Light & Power Co. The towers are connected to the city water main by a 6-in. supply line, and each system is equipped with a steamer connection for the use of the city fire department. In order to cover the yards thoroughly, the towers were spaced so that any car could be reached by at least two streams. Tests show that where the static pressure is only 65 lb., the nozzle pressure is 47 lb. and the discharge 255 gal. per minute. With a static pressure of 125 lb., the nozzle pressure is 88 lb. and the discharge 350 gal. per minute. Thus a car can be flooded with water at the rate of 400 gal. or 500 gal. per minute, making it almost impossible for fire to spread to neighboring cars.

A proposed layout for car-yard protection of the Cleveland (Ohio) Railway is shown in Fig. 17. The yard is 750 ft. long × 454 ft. wide, including car-inspection structure, offices and utilities buildings. The 18 standpipes are located around the yard at intervals of 90 ft. The standpipe nozzle tips are 1⅛ in. in diameter and the supply mains are of 8-in. and 6-in. diameter. Two hydrants are also installed to reinforce the interior sprinkler protection of buildings. The water supply is forced through the mains by a 750-gal. electrically driven underwriters' pump of centrifugal type, taking suction from a 75,000 gal. reservoir maintained on the premises. Under maximum pressure the fire pump will deliver 1000 gal. of water per minute, which can be concentrated on any one car in the yard. The installation cost of protection for the ultimate capacity of 175 cars will be about $20,000.

Standard fire hose and nozzles are the next best available protection. Hose should be 2½ in. for ordinary cases. Nozzles should be not less than 1⅛ in. Pressure should not be too great, because men who are not professional firemen cannot handle the nozzle under great pressure. Pressure at nozzle should probably be 40 lb. to 60 lb.

Open sprinklers operated by human agency are probably a very effective means for checking an early fire, and perhaps for extinguishing a fire which has gained more or less headway, but the cost appears to be too great for general use, although for small installations, where the sections are not large and where the controlling valves can be operated by hand the cost may warrant the use.

Details of Car-house Design

To design the most economical car-house building for a particular service in a particular location the designer must be able to design the several types of construction in detail and he must be able to estimate the costs of the materials and labor necessary for the finished structure. The general determination of this most economical design of car house consists in a determination of the most economical foundation, wall, form of roof and form of skylight. These individual parts must finally be considered with regard to their suitable relationship to each other. Among the general decisions which must be made at the outset by the designer are: Shall the building be short and wide or long and narrow? Shall two-, three- or four-track units be used? Shall the foundation be of stone, brick or concrete? Shall the walls be of brick, terra-cotta, concrete blocks, iron or concrete? Shall the roof framing be of wood, unprotected steel, protected steel, reinforced concrete or a combination of these? These must finally be decided with regard to their suitable relationship to each other. At the outset the designer should acquaint himself with the following: municipal regulations and building ordinances, rules and requirements of fire underwriters, character of soil upon which the foundation is to rest and the costs of materials and labor.

Figs. 18 and 19 show the construction of the Luzerne car house of the Philadelphia Rapid Transit Co. The girders, posts, roof slabs and floors are of reinforced concrete and the walls are of brick. The concrete portion was built by the unit method, whereby the concrete members are cast separately and lifted into place.

Fig. 20 shows the construction of the Middletown car house of the Connecticut Co. The floors and footings are of concrete, the walls are of brick and the roof is of mill type construction framed with yellow pine girders.

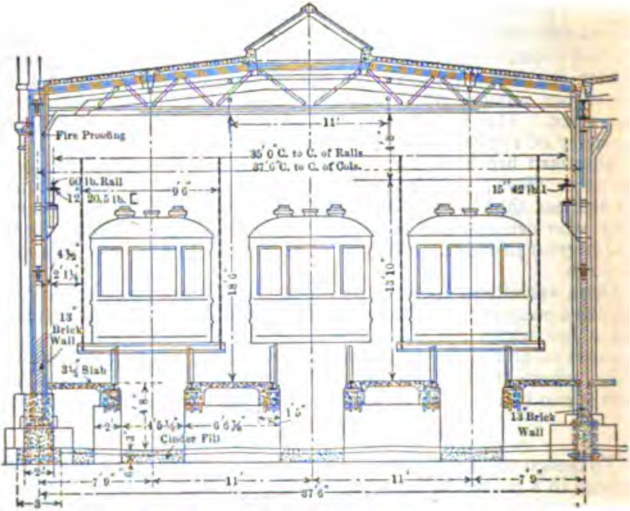


Fig. 18.—Luzerne car house, Philadelphia. Cross-section of bay for light repairs.

Foundations. If the soil is of good bearing capacity little study need be given to the matter of foundations. A car house is not a heavy structure, the walls being light, and the load of cars being well distributed by track work. The materials to be selected for foundations are largely determined by the supply near at hand. Concrete is probably as common and as satisfactory as any. Where soft yielding soil is encountered and piling found necessary, concrete piles have been used. In such cases and under certain conditions they undoubtedly prove more economical than wooden ones.

Walls. Brick masonry or concrete monolith seems to be the most suitable construction. If a cheaper form of wall is wanted, a heavy mill frame with a 2-in. cement plaster curtain makes a good fire-resisting scheme and one which is inexpensive to maintain. Corrugated iron is sometimes used, but is not recommended. There are in the market several forms of asbestos boards, but their cost does not warrant their selection in preference to masonry.

Roofs. A flat type of roof is the only suitable one for a car house. It should be as close to the trolley wire as possible. Light can be brought through the roof by means of skylights or monitors. The Am. El. Ry. Eng. Assn. committee strongly favored a mill type of heavy construction for the roof and advised against the use of steel.

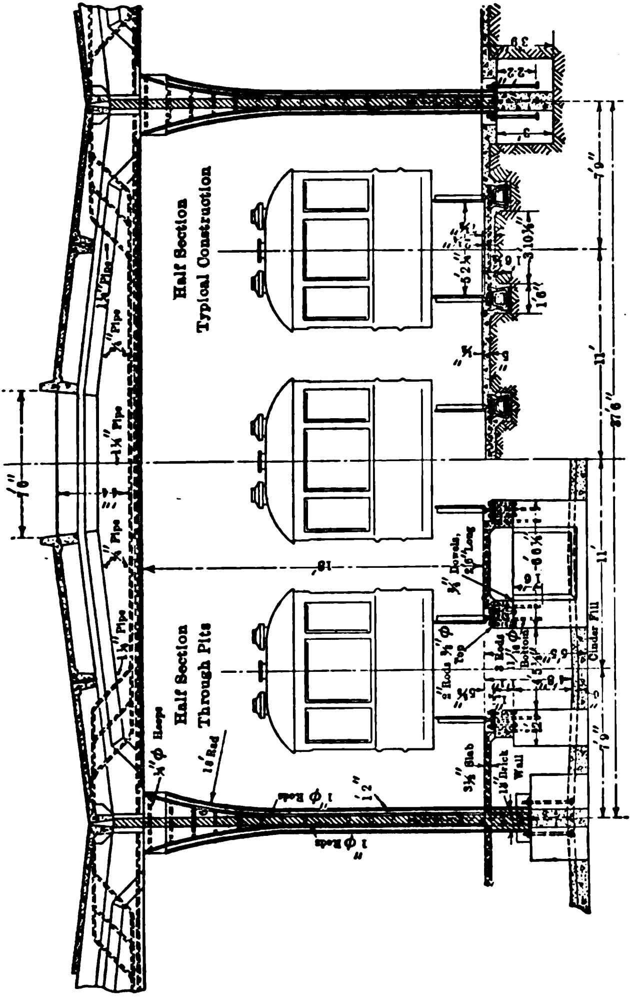


FIG. 19.—Luzerne car house, Philadelphia. Pit section and flush section of inspection bays.

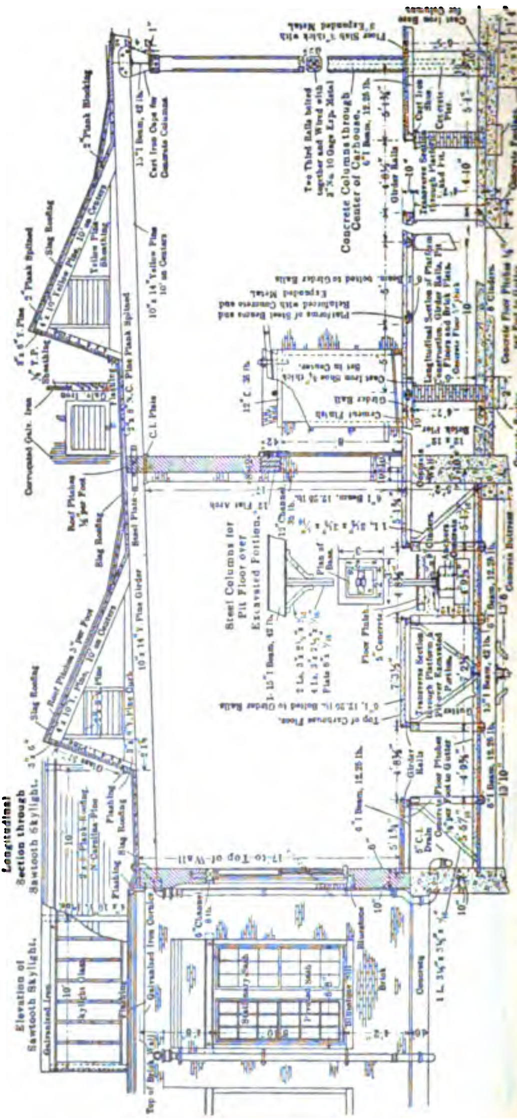
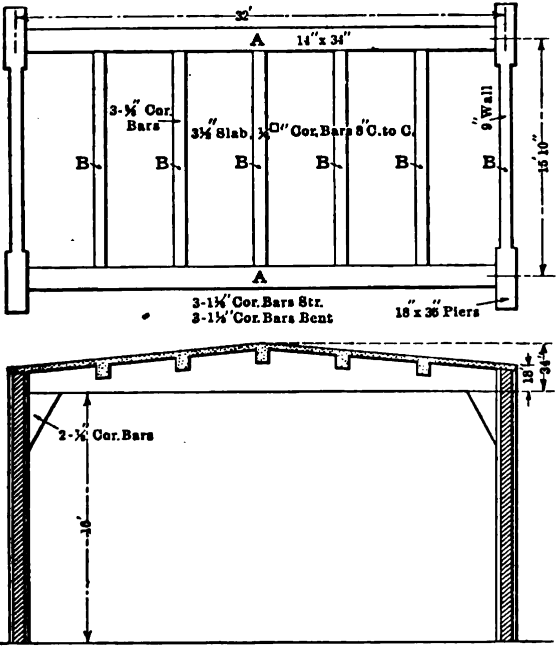

Elevation of Sawtooth Skylight.
Longitudinal Section through Sawtooth Skylight.
Slag Roofing
2" Plank Blocking
Yellow Pine Sheathing
Corrugated Galv. Iron
Roof Pitches ¼" per Foot
10"x 14" Y. Pine Girder
Steel Plate
C.L. Plate
15" I Beam, 42 lb.
Cast Iron Caps for Concrete Columns
10"x 14" Yellow Pine 10" on Centers
Steel Columns for Pit Floor over Excavated Portion.
12" Flat Arch
Plan of Base
Top of Carhouse Floor.
Floor Pitch ¼" per Foot to Gutter
Girder Rails
Concrete Footings
Concrete Footing
Brick Pier
Galvanized Iron Cornice
Stationary Sash
Pivoted Sash
Bluestone
Brick
Concrete
Skylight Glass
Galvanized Iron
Two Third Rails bolted together and Wired with 3" No. 10 Gage Exp. Metal
Concrete Columns through Center of Carhouse.
Floor Slab 5" thick with 3" Expanded Metal.
Cast Iron Base
Platforms of Steel Beams and Reinforced with Concrete and Expanded Metal.
Longitudinal Section of Platform Construction, Girder Rails, Pit Floors and Brick Piers.
Transverse Section through Platform and Pit Floor over Excavated Portion.
Cast Iron Shoe ½" thick Set in Cement
17'-to-Top of-Wall
6" Cinders
Concrete Buttress

FIG. 20.—Middletown car house, Connecticut Co.

The use of concrete for roof construction may be advantageous because of its fire-resisting quality. Its cost, however, may be prohibitive especially where long spans are necessary. Water should be taken off by valleys rather than by gutters and taken down within the building. For the covering of the roof there are a number of materials, all of which have some merit, but none of them are any

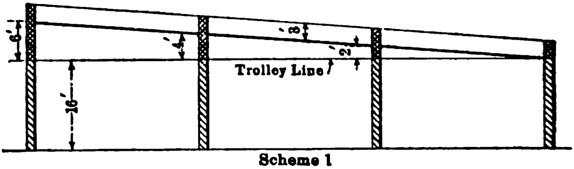


Concrete:	Quantity	Cost
Girder A, 26×14×36.15 ÷ 144	82	
Girder B, 5×8×14×14.66 ÷ 144	57	
Knees, 3×4×14 ÷ 12	14	
Slabs, 14.66×28.9×3.5 ÷ 12 − 4.75×4.66×3.5 ÷ 12	104	
Total concrete at 20 cents	257	$51.40
Steel:		
Girder A, 6 − 1 ⅛ c. r.×34	895.	
Girder B, 5×3 − ⅝ c. r.×17	344.	
Knees, 2×2 − ⅞ c. r.×9	95.5	
Slabs, 1×16×34× area ½ sq. c. b.	190.	
Total steel	1524.5	45.74
Forming:		
2560 b. m. at 25 cents per 1000 = 65 + 5 for knees		70.00
Total cost		$167.00
Total cost per sq. ft.		0.33

FIG. 21.—Typical study sheet for car-house construction material.

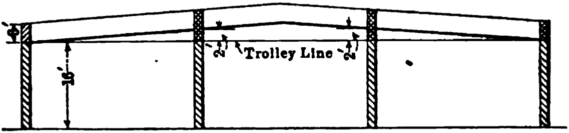
more satisfactory than a tar and gravel roofing well laid with first-class materials.

Fig. 21 by Messrs. C. A. Neff and T. P. Thompson, Electric Railway Journal, 1913, is a typical one of forty odd study sheets used by them in determining the proper roofing design for the car house of the Virginia Railway & Power Co. These sheets covered the various systems of steel supports with slabs, tile, plates as well as "monolithic" and "unit built" structures.



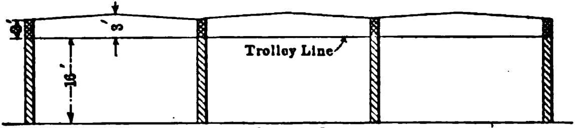
Scheme 1

Brick Work above Trolley Line Indicated thus........▨
(9+7+5+3)x 800 x 18 x .015 cts.=$5184.00



Scheme 2

Brick Work above Trolley Line Indicated thus..........▨
(3+5+5+3) x 800 x 18 x .015 cts.=$3456.00



Scheme 3

Brick Work above Trolley Line Indicated thus..........▨
(2+2+2+2) x 800 x 18 x .015 cts.=$1728.00

SUMMARY

Scheme No. 3 saves over scheme No. 1	$3,456.00
Scheme No. 3 saves over scheme No. 2	1,728.00
Scheme No. 3 saves over form of roof on certain car houses built by others	5,580.00

FIG. 22.—Typical study sheet for car-house roofing schemes.

Fig. 22 is a study sheet prepared by these engineers to show the results of an investigation of three different plans of roofing three units in one building. Scheme No. 1 shows the roof high on one side and sloping all one way. Scheme No. 2 shows the roof high in the center of the center unit and sloping two ways, scheme No. 3 shows the roof high over the center of each unit and sloping two ways over each unit. In each scheme the slope per foot is the same. As the necessary distance between track and trolley was fixed at 16 ft., it was considered that all wall used above the horizontal line 16 ft. above the tracks should be charged against each scheme in considering the relative cost. In scheme No. 3 there are only 2 ft. of brickwork above the trolley line at the outside wall, whereas in schemes Nos. 1 and 2 there are 3 ft. of brickwork. This results from the fact that in scheme No. 3 a girder 3 ft. deep in the center and only 2 ft. deep at the wall line was possible, whereas girders 3 ft. deep throughout were required in the other two schemes for the same strength. For purposes of comparison, the walls were considered as 13-in. brick walls, the figures being based on brick laid in the walls at $15 per 1000 and each wall being 400 ft. long.

Posts. The 1908 Am. El. Ry. Eng. Assn. committee favored the adoption of posts for the roof supports in preference to trusses. In the pit room they provide a means for supporting the car handling apparatus; they are convenient for holding the aisle sprinkler pipes, and also the standpipes and hose. They can also be used to support brackets for the fire pails. Where there are posts it is easy to introduce curtain walls, either the entire height of building or dropped down 6 ft. or more from the ceiling. Plaster concrete partitions along lines of roof posts make excellent fire curtains.

Trolley Troughs. One of the most satisfactory ways of holding up the trolley wire is by a suspended plank. The plank serves not only this purpose, but also when the trolley pole leaves the wire, prevents the grounding of current through contact of pole with sprinkler pipes, etc., in the building.

Bumpers. At the dead end of every track, and 3 ft. from the wall, there should be a stop to prevent the cars doing damage. There are several kinds of stops, such as the common cast-iron shoe bolted to the rail or fastened with clipping blocks, and bumping posts, consisting of hard pine timber buried in the ground or concrete. There is also the post secured with bolt and straps to the rail.

Doors. Doors are necessary for those portions of the house which have to be heated and those storage portions that are seldom used. They are less necessary on other parts of the house and may be omitted if one is satisfied that there is no fear of intrusion by those bent on thieving, setting fire or other malicious mischief. It is desirable to have the doors swing out. Both swinging and roller types of doors are being used. The former has many points in its favor, but the latter is a great convenience where room will not permit the use of swinging doors. Where swing doors are used they may be partly glazed. Roller type doors are sometimes motor driven for greater convenience and more rapid operation.

Floor construction (Recommended by Am. El. Ry. Eng. Assn., 1911, Committee on Buildings and Structures).

(*a*) *Car Houses.* Concrete floor with cement finish is best for permanent construction. Otherwise crushed stone and screenings, or ashes is advised.

(*b*) *Car Shops.* Concrete floor with cement finish is recommended, except in machine shop, if subjected to heavy service, where creosoted wood block on concrete foundation should be installed.

(*c*) *Power Houses.* For engine room, concrete with cement or tile finish is advised. For boiler room, concrete and cement finish or a floor of brick laid on edge in cement mortar is recommended.

(*d*) *Offices, Employees' Room, etc.* Maple or combed-grain yellow pine wearing floor should be used. If wearing floor is supported by sleepers embedded in concrete, it is always best to install a false floor underneath the wearing floor.

(*e*) *Toilet and locker room floors* should be of concrete with cement finish, and connected with sink and trap to drain, so that the floor may be conveniently washed and scrubbed down.

(*f*) *For waiting rooms or shelters and platforms,* floors of concrete and cement finish are recommended for permanent structures. Rolled broken stone and screenings or ashes may be satisfactorily installed for cheap open shelters for temporary construction.

Lobbies. As already stated, the lobby should be under the eyes of a supervising official; and any plan by which the men are left to themselves is undesirable. The lobby should be provided with seats, tables, bulletin boards, and the like; counters should be arranged for the filing of time sheets and other papers requiring the signatures of conductors. All seats are better attached to the wall for the sake of cleanliness. Metal lockers should be provided directly in the lobby or in an adjoining room. For those men who are of a quiet disposition a separate room should be provided, where reading and the playing of quiet games can be indulged in. This room should have a table for letter writing. Separate rooms are also advisable for making out time sheets, reports and accident blanks. All parts of the lobbies and toilets should be so designed as to suffer as little as possible from the destructive work of idle hands. Adjoining the lobby should be ample toilet facilities, with provisions to keep the same in sanitary condition. The floor should be such as to admit flushing; partitions should not run to the floor; as little wood as possible should be used; sharp corners should be avoided; and there should be good provisions for light and air. In the larger houses there should be equally well-planned toilets adjoining the pit room, and possibly a private toilet for the officials. If the house is small a central toilet with one or two water closets under lock and key may answer for all employees.

Pits. The pit room, one of the most important parts of the house, should be placed well back, and the area should represent a capacity of at least one-third—or, better, one-half—of the car storage. It should be well lighted, to save artificial light, and amply heated for the sake of the comfort of the men and for the melting of the snow around the trucks. Pits should have an average depth of 4 ft. 6 in. from the top of the rail. Preferably, the floors of the pits should be of concrete and slightly crowned to shed water. The main floor on one or more tracks should be dropped next to the rail on each side of the pit to facilitate working about the truck and the running boards. Fig. 23 shows a drop floor at the side of the pit. This floor is 27 in. below the top of the rail. It can be less if preferred, and with some equipments 12 in. proves satisfactory. The natural lighting for the pit room is through the monitor of saw-tooth type with vertical glass. A cross, or transverse pit, with the floor slightly below the floor of pit and terminating in a room at the side, is a convenience for moving material from pit to pit. The room can be used for storage or, if well lighted, for a work room. An opening can be provided so that material can be lifted to the floor above. By referring to Figs. 23 to 29, several schemes of pit construction will be found illustrated. (See also Figs. 18, 19 and 20.) A form of construction that utilizes the rail for the support of the floor, as well as taking the cars, will be found simple and economical. It also does not pocket the heat under the floor and gives greater clearance for working and for passing from pit to pit. In the form of pit construction shown by Fig. 29, a single pit sufficient in size to cover all tracks is constructed in the car-house floor. Tracks over this pit are supported on columns made of a single 3 × 3 × 5/16 in. angle with a gusset plate at the top to serve as a point for attaching a strut, two diagonal tie rods and the rail clips. Two angle lugs at the bottom serve to spread the load on the concrete pedestals and as a means of anchoring the supporting structure to the pedestal foundations. These track columns are spaced 9 ft. 6 in. apart and are built in bents similar to bridge buck braces. They are paired to support the rails of parallel tracks, and are stiffened diagonally by round tie rods with turnbuckles for adjustment. A 4 × 3 × 5/16 in. angle between columns serves as a strut to prevent overturning and as a support for the walkway between the tracks. In order to provide sufficient girder strength between the pit columns 100 lb. A.S.C.E. rail has be-

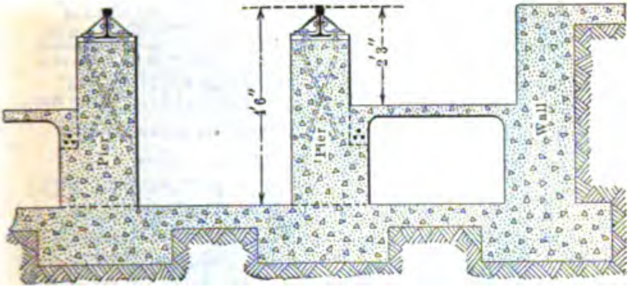


FIG. 23.—Section showing drop floor beside pit.

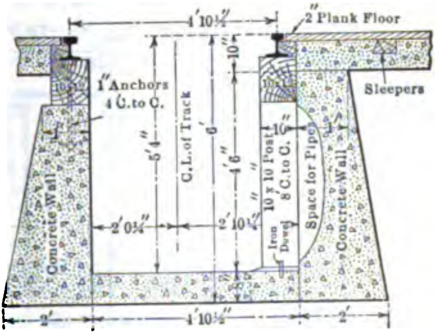
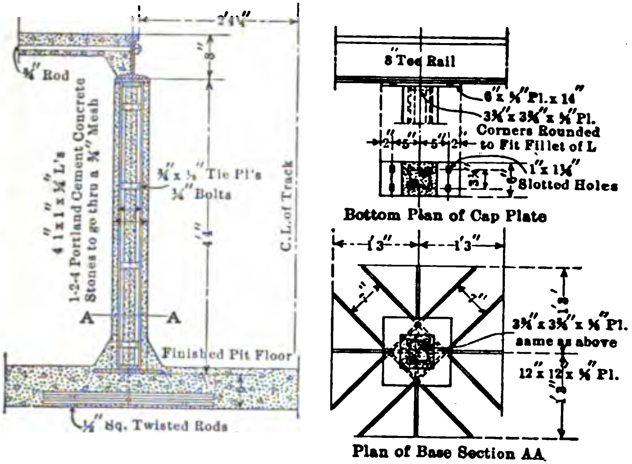


FIG. 24.—Section of pit construction deeper and more expensive than usual supports.

When reinforcing rods are used, pier foundations are unnecessary. Entire concrete pit floor can be laid and pit piers or columns erected later, which will reduce the cost of construction materially.



Bottom Plan of Cap Plate

Plan of Base Section AA

FIG. 25.

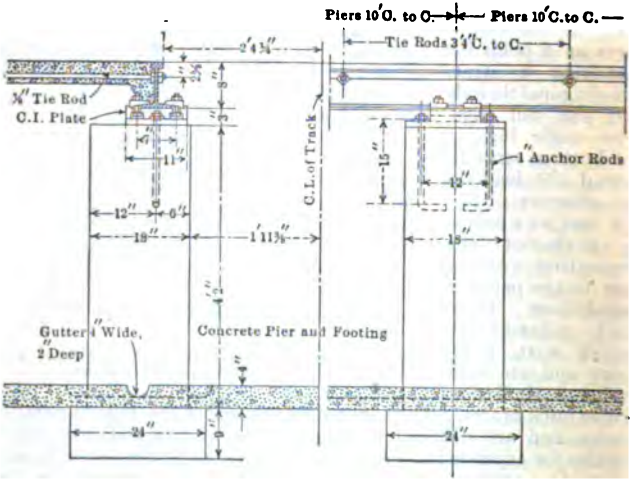
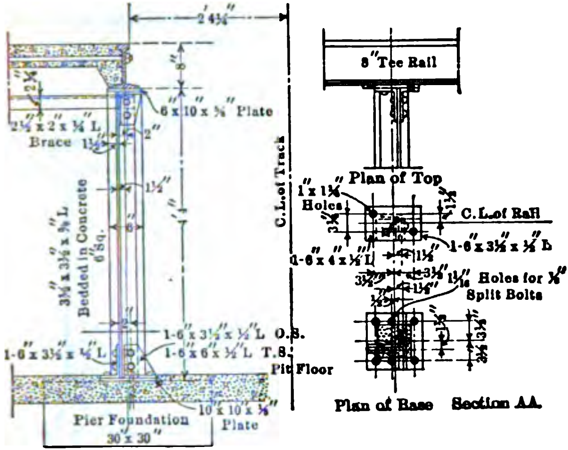


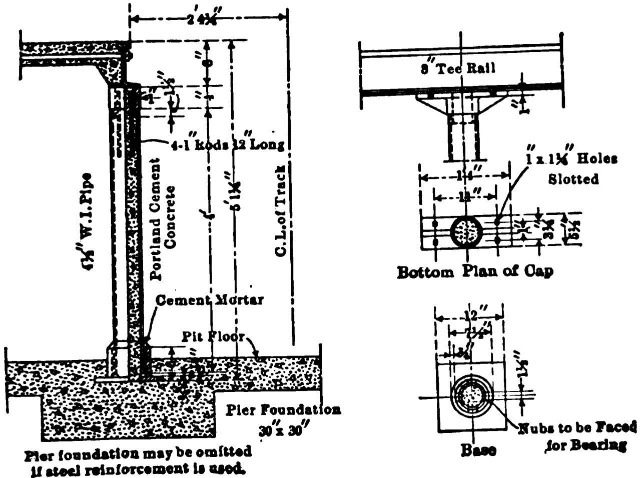
FIG. 26.

FIGS. 25, 26.—Types of pit construction with 8-in. T-rail on pier or column supports.



Pier foundation may be omitted if steel reinforcement is used.

FIG. 27.



Pier foundation may be omitted if steel reinforcement is used.

FIG. 28.

FIGS. 27, 28.—Types of pit construction with 8-in. T-rail on pier or column supports.

used to span the 9-ft. 6-in. interval between them. The method of fastening the rail at the columns is by means of clips bolted to the horizontal leg of the structural angle strut.

Sand. It is important to provide for the storage and drying of sand. The apparatus for the drying should be placed close to the operating end of the house and should allow circulation of air as well as of heat. The process of drying is slow at the best, so that it is well to have a large storage space adjacent to the heater. This space should be filled with air-dried sand in the summer, and, with the assistance of the heater, an ample supply can be kept on hand during the winter. In the Luzerne car house of the Philadelphia Rapid Transit Co., an elaborate sand-storage and distributing equipment has been installed to make it easy for the crews to fill their boxes with clean sand in the shortest possible time and without placing bins throughout the building.

For this purpose the company built a sand house where the sand brought from the drying plant in hopper-bottomed cars is dumped and then raised by a motor-driven bucket elevator to a belt conveyor which distributes its load throughout the sand-handling panel extending across the rear of the car house. This panel is 16 ft. wide and is lighted by means of steel-sash windows in the rear wall. Outlets from the bottom of the sand storage are provided at the partition walls with a supply pipe for each side of the partition. To obtain sand, it is necessary only to raise a weighted valve and the sand receptacle will be filled.

Salt. Less space is required for the storage of salt, but full provision for its handling is just as necessary.

Heating systems recommended (by Am. El. Ry. Eng. Assn., 1911, Committee on Buildings and Structures):

(*a*) For car houses, a blower system, where the air is blown over steam coils and through the building.

(*b*) Large car shops, the blower system, except in the paint shop, where direct steam radiation is advised. For the small shop, either direct steam or a hot water heating system.

(*c*) Isolated waiting rooms, only practicable to heat if attended—generally, standard coal stoves are advisable. If waiting room is large and pretentious, steam or hot water heating system may be used.

(*d*) Unisolated waiting rooms. Direct steam or hot water system is generally advisable.

(*e*) Small isolated ticket booths and the like may be satisfactorily heated with the ordinary electric car heater.

Lighting. The pit room should be well lighted, but a proper disposition of lights will make their number comparatively small. One satisfactory and economical arrangement is to place lamps on one side of pit about 18 ft. on centers. Each lamp is portable and enables the inspector to place it close to any desired point, and a hook attached to the lamp allows it to be hung up. Sufficient light should be provided in those places where trolleys are usually shifted. For the sake of the eyes, light should not be stinted in the reading, report and other rooms attached to the lobbies. All interior wiring should be installed in conduits.

Road and Line Departments. When quarters for the road and line departments are to be furnished, they should be placed so as to have yard room adjoining. The headquarters themselves should be of ample size to take the more or less bulky materials that are used.

Proper provisions should also be made for the locking up of copper and other valuable portions of the stock.

Express Accommodations. Companies doing or contemplating doing an express business may wish to establish a terminal at the car house. In such cases the room should be so situated that the express cars and teams receiving and delivering shall not interfere with the operation of the regular cars, and will not be in the way of future improvements of the house. It should also be placed so that the clerk in charge could, if he had spare time, do other duties connected with the general routine.

Repair-shop Design

The following excellent compilation of figures from ten electric railway repair shops, giving consideration to relative areas of different departments, as well as to ground and building areas, is taken from the Electric Railway Journal, 1912:

It is believed that past experience has, by a process of elimination and addition, determined approximately correct areas for the various shop departments, and, in consequence, a series of averages taken from representative repair shops should determine a definite standard which may be expressed in exact terms. It is, of course, true that the individual ideas of different designers as well as local conditions have affected the arrangement and proportions of existing shops, but, in a set of averages from any large number of arrangements, these variations cancel out and become negligible in the general result. In order to obtain figures upon which to base averages, ten shops have been selected as representative. These are shown in the following table, which also gives the reference to the files of the Electric Railway Journal, where descriptions of the different shops may be found:

Shop	Fig.	Railway	Reference
Milwaukee.....	33	Milwaukee Electric Ry. & Lt. Co.	Feb. 4, 1911, p. 206
Baltimore......	32	United Railways and Electric Co.	Apr. 4, 1903, p. 512
Seattle.........	35	Seattle Electric Co........	Oct. 2, 1909, p. 537
Rochester......	36	New York State Railways..	Apr. 11, 1903, p. 549
Anderson......	40	Union Traction Co. of Ind.	Apr. 4, 1908, p. 540
Minneapolis....	39	Twin City Rapid Transit Co.	Oct. 10, 1908, p. 891
Portland.......	34	Portland Railroad Co......	Nov. 26, 1910, p. 1057
Syracuse.......	37	Oneida Railway Co........	Apr. 1, 1911, p. 551
Chicago.......	31	Chicago Railways Co......	Mar. 25, 1911, p. 492
Montreal......	38	Montreal St. Ry. Co.......	Oct. 29, 1910, p. 908

Proportions. For the purposes of comparison each one of the ten shops has been divided into eight different departments, namely, (1) repair shop, (2) machine shop, (3) blacksmith shop, (4) carpenter or erecting shop, (5) storeroom, (6) armature room or electrical department, (7) wood mill, (8) paint shop and wash rooms. The repair shop is intended to include the building or area where general repair work is done upon cars. It includes the truck shop and the space provided for floor work on running gears, brake rigging and such

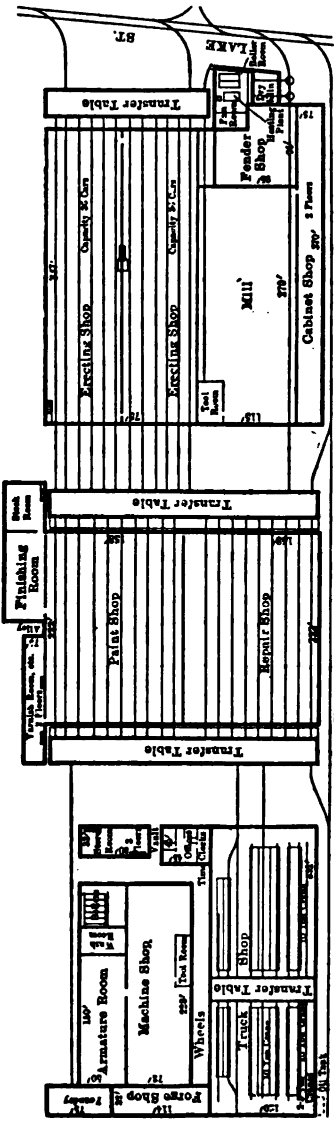


Fig. 31.—Chicago shop arrangement.

repair work on controller wiring, sand boxes, railways, door rigging and the like as can be done either upon the car or without necessity for use of special appliances available in other departments. The machine shop and the blacksmith shop cover the space assigned to metal-working machinery, including the wheel shop. The carpenter or erecting shop provides space for heavy repairs upon car bodies and is distinct from the repair shop in that in the latter only light carpentry repairs which will not hold the car are done as needed. The storeroom is the building or room where stock material is kept and does not include storage space outside for heavy materials nor the interior space used for storing material immediately needed in the different departments such as bar iron for the blacksmiths and unmounted wheels at the wheel press. It does, however, generally include the shop offices. The armature room is intended to include space for strictly electrical repairs although the line of demarcation between this department and the machine shop is not well defined on account of the machine shop work in stripping and testing motors, turning and slotting commutators and the like. The wood mill covers the space assigned to wood-working machinery and includes the cabinet shop wherever a separate room is installed for that work. The paint shop and wash room, in addition to the work indicated by the title, includes paint mixing and storage space, room for sash, doors and seat storage and the varnishing rooms. Of the minor departments the dry kiln and heating boilers, being subject to arbitrary considerations, are omitted in making up averages. The tin shop has been included with the blacksmith shop when possible, and the brass foundry, where one is installed, has been omitted, as its existence depends upon whether it is the policy of the company to purchase or manufacture its brass fittings. Space devoted to inspection of cars or storage of cars has been omitted in every case for the same reason, as these are operating and not strictly repair-shop facilities.

On this basis the area of each department of each of the ten shops has been determined and the relative area of each department has been expressed as a percentage of the total area of the shop. These percentages are shown in the following table:

Relative Area of Departments Expressed as Percentage of Total Shop Area

	Repair shop	Machine shop	Blacksmith shop	Carpenter shop	Storeroom	Armature room	Wood mill	Paint shop and washroom
Milwaukee...	19.6	12.9	5.9	18.3	13.8	5.2	6.9	17.4
Baltimore....	17.9	7.4	3.7	17.9	12.4	4.8	12.8	23.1
Seattle......	17.4	10.8	3.1	13.9	18.1	6.5	7.0	23.2
Rochester....	21.0	13.6	2.3	10.5	30.4	3.2	5.6	13.4
Anderson.....	22.0	8.3	3.3	17.5	16.4	5.6	9.7	17.2
Minneapolis	9.5	8.3	7.1	17.7	17.8	8.3	8.9	22.4
Portland.....	19.5	8.4	6.2	10.7	11.5	8.3	7.8	27.6
Syracuse.....	30.2	5.5	1.5	18.7	18.5	1.5	2.4	21.7
Chicago.....	21.1	12.6	1.4	22.5	4.8	4.1	15.2	18.3
Montreal....	23.3	8.6	4.9	19.0	10.6	5.5	7.6	20.5
Averages...	20.3	9.4	4.0	16.8	14.9	5.3	8.2	21.1

The list of shops shown has been made up without regard to size or the number, type or size of the cars served by it. It is possible that these factors may influence the relative areas of the different departments, but the table shows that any such influence is very slight. This may be accounted for by the fact that large cars will have large motors and heavy trucks and wheels. Large cars will also contain more wood than small ones, and all departments will increase in approximately the same proportion as more shop space is required to house the car bodies.

Exceptions from the General Average. With few exceptions all the shops seem to agree reasonably well with the average. Notable among the exceptions are the Minneapolis and Syracuse shops with repair departments respectively 50 per cent. and 150 per cent. of the areas indicated as good practice by the average of the table. The former is accounted for by the fact that part of a car house not shown on the drawing of the Minneapolis shops is used as a light repair shop. Since the area devoted to this purpose is unfortunately indeterminate, it has not been added in the repair shop area. The

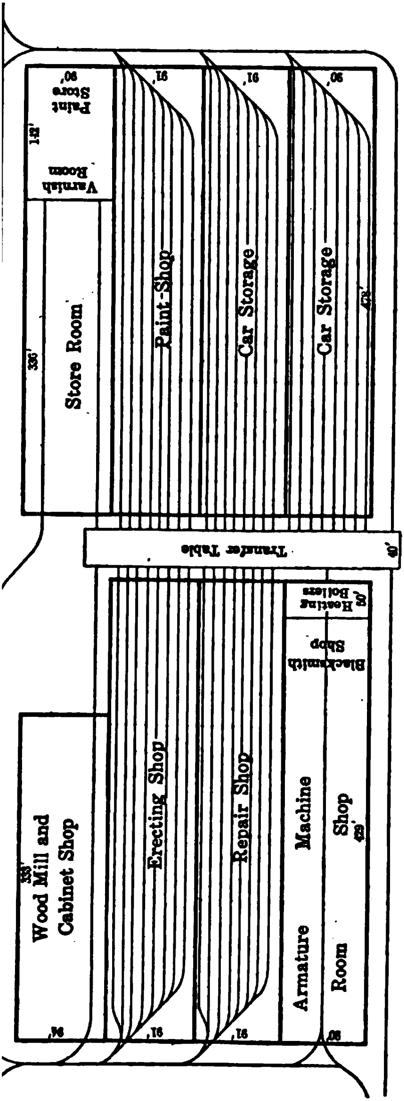


FIG. 32.—Baltimore shop arrangement.

large size of the repair shop at Syracuse, on the other hand, has resulted in the space between the tracks being used for storage of various heavy materials. It is manifestly not a crowded department. An exception in the case of machine shop area will be found at Syracuse where no floor work is done in the machine shop. It is not necessary in this case, as there is ample room for that purpose in the unusually large repair shop adjacent to it. Two very small blacksmith shops are found in the cases of Syracuse and Chicago. At Syracuse contracts are made with outside local smithies for much of the blacksmith work and naturally only limited space is necessary. In Chicago the blacksmith shop is reported by the chief engineer of the Chicago Railways Company to be badly crowded just as is indicated by the figures and it is to be extended in the near future. The large blacksmith shop at Minneapolis can be accounted for by the fact that a large amount of manufacturing is done in the shop. All carpenter shops seem to run reasonably close to the average, except possibly Portland, which is a small shop and not subject to any strict lines of demarcation between departments, and Rochester, which has small cars and narrow track spacing in the carpenter shop. The exceptions to the rule in the case of storehouse areas are at Chicago and Rochester. The first may be accounted for by the fact that the shops are located in a large city where purchase of materials of all kinds can be made on short notice, as well as the fact that the company has other storehouses at different points on its lines. The large storage area at Rochester is clearly due to the fact that no material is stored outside the building, it being placed in a basement extending under the entire shop. Syracuse is again in evidence with an exceptionally small armature room, which is stated to be ample in size for the reason that no electrical equipment on the cars is overloaded or subjected to other abuse. It is reported that no motors are ever rewound at these shops. Syracuse and Chicago show extreme variations from normal in the size of the wood mill. At the former place no reason is assigned for this, although it is reported by the management to be very compact in arrangement. At Chicago the mill was purposely laid out

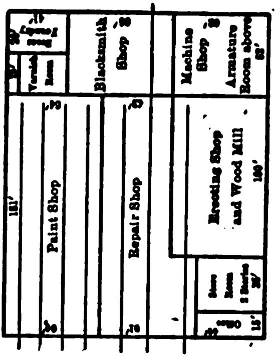


FIG. 34.—Portland shop arrangement.

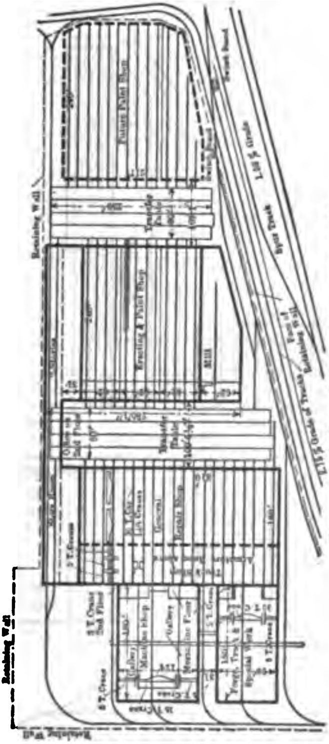


FIG. 33.—Milwaukee shop arrangement.

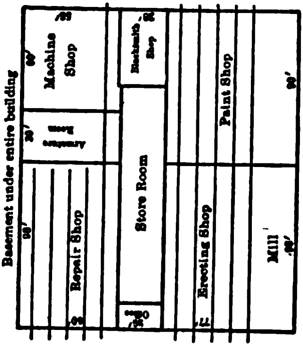


Fig. 36.—Rochester shop arrangement.

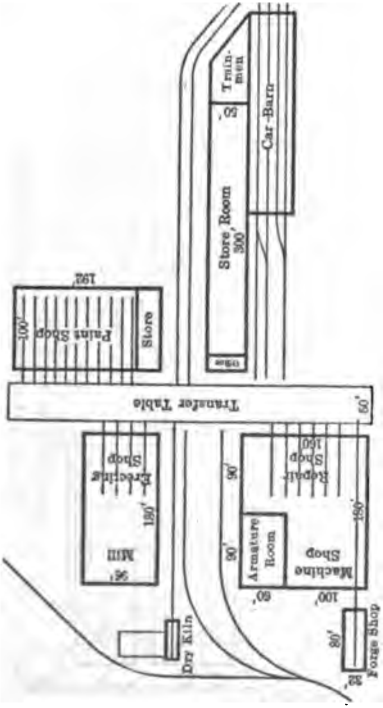


Fig. 35.—Seattle shop arrangement.

so as to permit wagons to pass between the machines, and space for storing 50,000 ft. of lumber on the mill floor is provided. This naturally follows from the fact that no lumber storage could be provided outside on account of location in a congested city. The paint shops in every case except Rochester run reasonably close to the average, the maximum being 25 per cent. above and the minimum 21 per cent. below normal. The limited area of paint shop at Rochester may be accounted for on the same ground as the small carpenter shop at this point, namely, small cars and close track spacing. From the foregoing it appears that a distinct relation between the areas of the various departments in repair shops has become established and that present practice in the matter is reasonably well standardized.

Size of Buildings. The actual areas of the building or buildings required for housing the various departments of the repair shop of any electric railway are, of course, subject to a number of obscure factors. Probably the easiest way to arrive at a basis for comparison is to consider the areas in square feet per car served by the shop.

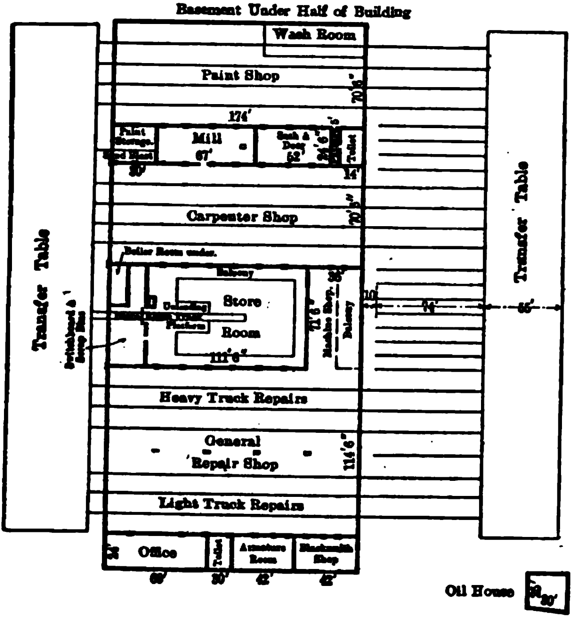


Fig. 37.—Syracuse shop arrangement.

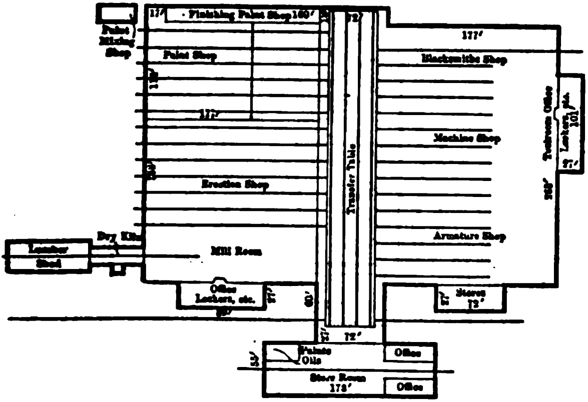


Fig. 38.—Montreal shop arrangement.

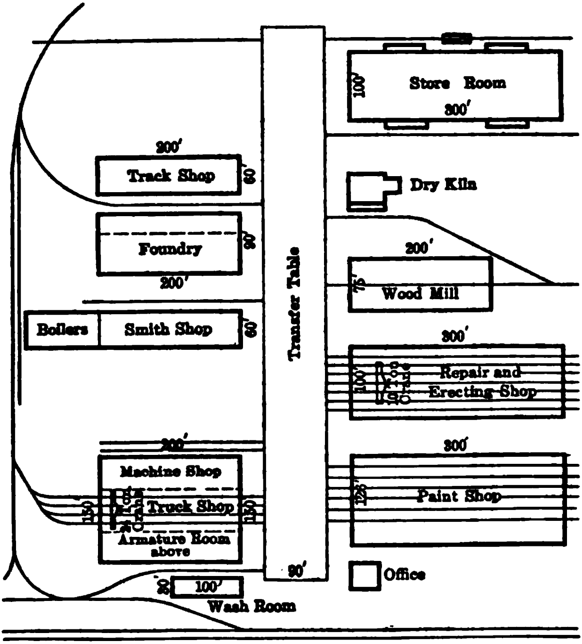


Fig. 39.—Minneapolis shop arrangement.

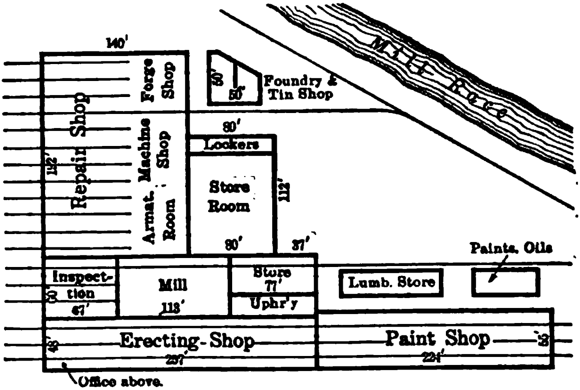


Fig. 40.—Anderson shop arrangement.

It is granted that this is an exceedingly rough, approximate method, but, in view of the fact that there is necessarily a certain relationship between size of shop and number of cars, a table has been prepared to show the range through which this unit varies. In determining the areas given, only buildings have been included. No yard space of any kind is considered, and covered transfer tables where they exist have been omitted.

Relation of Shop Areas to Total Number of Cars Owned by the Railway

Shop	Number of cars owned	Floor area of shop	Square feet of shop per car
Milwaukee(*a*)	1,500	284,600	190
Baltimore	1,780	243,400	137[1]
Seattle	450	82,900	184
Rochester(*b*) (*c*)	236	56,000	237
Anderson	300	70,200	244
Minneapolis	787	168,800	215
Portland	210	38,400	183
Syracuse(*c*)	250	65,900	264
Chicago	2,200	262,100	120[2]
Montreal	570	111,500	196
Average of results			197
Totals	8,283	1,383,800	167

(*a*) Number of cars estimated. (*b*) Number of cars based on annual output of shop. (*c*) Floor area includes part basement.

[1] Two bays used for car storage not included.

[2] All light repairs are made at car houses.

With the exception of Baltimore and Chicago, all shops seem to have an area approximating 200 sq. ft. per car owned. At Baltimore the tracks are spaced on 10-ft. 6-in. centers and this is unquestionably too narrow for efficient operation. If the track spacing were increased to the customary 16 ft., the area occupied by cars would be increased 50 per cent. As will be shown later, the space occupied by cars is approximately half of the total shop area so that the wider track centers distances would increase the total area 25 per cent. and bring the area per car up to 172 sq. ft. At Chicago considerable work is done in the outside car houses. This includes all light repairs, installing wheels, armatures and motors and overhauling trucks, so that the main shop is relieved to a considerable extent.

Influence of Various Factors on Size of Shop. The same result may be arrived at in a somewhat different manner by assuming that each car in the shop occupies a space 60 ft. long and 15 ft. wide. The length of 60 ft. is based on a 45-ft. car body with a 7-ft. 6-in. space at each end for passageway, trucks and waste room. The width is assumed arbitrarily from the track spacing existing in many shops. This gives a total area of 900 sq. ft. required for each car which stands in the shop. However, the whole of the shop is not devoted to housing car bodies, and by referring to the first table the average condition will be found to be as follows:

Space not used for cars

	Per cent.
Machine shop	9.4
Blacksmith	4.0
Storeroom	14.9
Armature room	5.3
Wood mill	8.2
Cabinet shop, varnish rooms, etc., say 15 per cent. of paint shop	3.3
Truck shop, say 25 per cent. of repair shop	5.0
Total	50.1

In other words, approximately half of the shop is used for housing cars and the other half for machinery and floor work. If each car requires 900 sq. ft. of space in which to stand, the total area of shop for each car contained in it will be twice that, or approximately 1800 sq. ft. Then, if 10 per cent. of the equipment is held in the shop at any one time for repairs, accidents or rebuilding, 10 per cent. of 1800 sq. ft. of shop area will have to be provided for each car owned. This amounts to 180 sq. ft. of shop per car, which checks fairly well with the figures indicated in the preceding table. This is undoubtedly the most accurate method for arriving at the proper size of shop for any electric railway, as it permits allowance for the requirements of variations in length of car body as well as for unusual conditions which might necessitate frequent shoppings due to numerous accidents or excessive wear. The latter allowance may be made by using judgment in selecting the expected percentage of cars held in the shop. In crowded city streets, for instance, where accidents are common, it would not be unreasonable to assume that 12 per cent. of the cars owned might be held in the shop. On the other hand, where equipment is first class and conditions good, it is safe to reduce the figure to 8 per cent. This method can be expressed by the formula:

Shop area in square feet $= 2 \times L \times S \times C \times P$

where L = length of average car plus 15 ft.
S = track spacing (generally 15 ft.)
C = number of cars owned by the railway
P = maximum percentage of cars held out of service in the shop (generally 10 per cent.).

As a further check on these figures the following table has been prepared to show the approximate capacity in cars of each of the ten shops here considered, also the percentage of the total number of cars held in the shop and the number of square feet of shop for each car which it can hold. The figures in column 6 are obtained by dividing those in column 4 by those in column 5. The figures in column 8 are obtained by dividing the figures in column 7 by those in column 4.

The figures in column 8, or the area of shop per car housed, correspond to the value $2 \times L \times S$ given in the formula and are comparable to the figure of 1800 mentioned in the example previous to that. The figures in column 6, or the percentage of cars owned which can be housed in the shop, correspond to the term P in the formula. The fact that the Syracuse shops can hold over 17 per cent. of the cars on the road is not necessarily evidence that they ever do so. The peculiarly large repair shop at Syracuse accounts for this condition; for, while this department has capacity for eighteen cars, there is no indication that it ever needs to hold over eight. The low area of shop at Baltimore per car contained, as shown in column 8, may be accounted for by the fact that the shop tracks are set on 10-ft. 6-in. centers. The latest practice calls for 15-ft. and 16-ft. centers, and this would add about 25 per cent. to the figures shown.

RELATION OF SHOP AREA AND NUMBER OF CARS OWNED TO THE NUMBER OF CARS WHICH SHOP WILL CONTAIN.

	Capacity in car (50 ft. long)							
	(1) Repair shop	(2) Erecting shop	(3) Paint shop	(4) Total No. of cars held by shop	(5) Total No. of cars owned by road	(6) Per cent. of all cars held by shop	(7) Area of shop in sq. ft.	(8) Sq. ft. of shop per car contained in it
Milwaukee...	40	48	52	140	1,500	9.3	284,600	2,030
Baltimore....	56	64	64	184	1,780	10.8	243,400	1,320
Seattle......	7	8	22	37	450	8.2	82,900	2,240
Rochester....	5	10	10	25	236	10.6	56,000	2,370
Anderson....	12	12	12	36	300	12.0	70,200	1,950
Minneapolis	......	35	36	71	787	8.9	168,800	2,370
Portland.....	4	3	12	19	210	9.0	38,400	1,940
Syracuse.....	18	12	14	44	250	17.6	65,900	1,500
Chicago.....	36	72	50	158	2,200	7.2	262,100	1,650
Montreal....	15	21	18	54	570	9.5	111,500	2,070
Averages...	19	28	29	76	......	10.3	....	1,944

Ground Areas. In the foregoing only the areas of buildings or floor areas of the various departments have been considered. It is, of course, undesirable to build a shop upon a plot of ground of the exact size of the building. There are many classes of material, such as wheels, iron castings, lumber, scrap and the like, which can be conveniently stored outside of the shop building, and this is undoubtedly better than to have them occupying valuable space under a roof, or to have them kept in a storeyard at some distance from the shop. In addition to this it is not unusual to make use of the shops for storing and repairing track material so that a need exists for a plot of ground considerably larger than the shop buildings. Unfortunately no set relation appears to exist between building and ground areas. However, the following table has been prepared to give a conception of present practice in regard to the total area of ground required. The figures have been worked out in three ways, each column showing the same area expressed in different form.

It will be noticed from this table that a marked difference in area of ground required exists between those shops which are composed of separate buildings and those in which all departments are grouped

Areas of Shop Grounds

	Area of ground and buildings, acres	Per cent. of building area	Area per 100 cars owned, acres	Area per car owned, sq. ft.	Remarks
Milwaukee.....	9.5	144	0.63	273	
Baltimore.....	11.9	214	0.67	292	
Seattle........	9.0	470	2.00	870	Separate buildings
Rochester.....	0.9	115	0.31	133	Basement area not included. No transfer table.
Anderson......	5.5	342	1.83	800	
Minneapolis...	19.7	510	2.50	1090	Separate buildings. Includes track material.
Syracuse......	3.6	236	1.44	620	
Chicago.......	11.0	180	0.49	214	Basement area not included.

under one roof or are located in two or three large buildings separated only by narrow transfer tables. The former arrangement offers a much greater protection against disastrous fires, permits better natural lighting facilities and, especially for large shops, gives an opportunity for greater flexibility in design. However, it appears that the spaces between the different buildings are not needed aside from their value for fire protection, and that separating departments in different buildings necessitates a considerably greater ground area for the shops. The low figure of 0.31 acre per 100 cars owned which is shown for Rochester is due to the fact that this shop has a basement extending under the entire shop building. This in effect makes a two-story shop and, as has been mentioned before, gives the shop an unusually large storeroom. The area outside of the shop usually allowed for heavy storage has in this case been put into a basement. The same arrangement obtains in a limited degree at Syracuse, where part of the shop building is provided with a storage basement. Chicago has a lay-out characterized by decidedly restricted building area in consideration of the total number of cars owned, so that it is evident that the minimum ground area required for a complete set of shops is somewhere between 0.49 acre per 100 cars owned, as at Chicago, and 1.83 acres, as at Anderson. The latter shop, as shown in the cut, is located on a triangular plot of ground which is at best difficult to utilize. In round numbers, it is probable that 1 acre per 100 cars owned is sufficient, or at least desirable, for a compactly designed shop. When separate buildings are used for the different departments, and especially where considerable quantities of track material are stored, 2 acres per 100 cars owned appears to be the least possible ground area which should be provided.

Miscellaneous Departments. The dry kiln lumber store, boiler room and brass foundry, as already stated, are departments whose areas are not necessarily dependent upon the considerations affecting the proportions of the rest of the shop. Where the information can be obtained the areas of these minor departments are as follows:

AREAS OF MISCELLANEOUS DEPARTMENTS (SQUARE FEET)

	Dry kiln	Lumber room	Boiler room	Percentage of total building area occupied by boilers	Brass foundry	Pattern store	Toilet and locker rooms	Percentage of total building area occupied by toilet facilities
Milwaukee	....	......	......	....	......	......	2620	1
Baltimore	....	......	4500	2	......	......	5000	2
Seattle	....	......	......	....	600	......	......	....
Rochester	....	......	1250	2	......	......	......	....
Anderson	....	2500	......	....	1250	......	1200	2
Minneapolis	4900	......	6000	4	......	......	3000	2
Portland	....	......	......	....	1100	......	......	....
Syracuse	....	......	1500	2	......	......	700	1
Chicago	1000	......	1500	0.5	2400	7500	2200	1
Montreal	1000	3000	......	....	......	......	2000	2

Provision for Growth. Examinations of the shop arrangements shown in Figs. 31 to 40 disclose the somewhat unexpected condition that only a minority of the ten contain distinct provision for future extension. It is, of course, possible to extend any shop provided that sufficient ground area is provided around it, but in most of the layouts shown an extension could only be made by shifting departments or adding to the sides instead of the length of the buildings.

Miscellaneous Considerations. A number of features of the different shops under consideration affect indirectly the areas of the different departments, and for that reason they are shown in the table on the following page.

The matter of track spacing, or the distances between centers of tracks, is the most important matter covered in the table. The average for all of the ten shops is approximately 14 ft. 6 in. for all departments. However, of the ten shops, Baltimore and Rochester were built prior to 1903, or more than 5 years before the other eight. The present tendency seems to be strongly in favor of a wider spacing. If these two shops are omitted, the average spacing becomes as follows:

Repair shop	15 ft. 7 in. c. to c.
Erecting shop	15 ft. 5 in. c. to c.
Paint shop	15 ft. 1 in. c. to c.

Of the methods used for raising cars off trucks, electric traveling cranes or hoists appear generally to be preferred. However, their use does not actually tend toward compactness of shop. Crane installations are not confined to the largest plants, although it would seem that they are peculiarly adapted to such shops. Transfer tables are used by seven out of ten shops in preference to ladder tracks. This preponderance of opinion is evidently due not only to the convenience and speed of the transfer table but also to the high cost of the complicated overhead work and switches necessary without it. The location of armature rooms on a gallery or secon

Factors Indirectly Affecting Shop Areas

	Track spacing							Use of tracks which hold more than two cars		
	Repair	Erecting	Paint	Per cent. of tracks with pits	Methods of lifting cars off trucks	Transfer table provided	Armature room on second floor	Repair	Erecting	Paint
Milwaukee..	15½	15½	15½	29	Traveling electric cranes	Yes	Yes	....	Yes	Yes
Baltimore...	10½	10½	10½	66	Chain hoist	Yes	......	Yes	Yes	Yes
Seattle.....	16	16	14	.....	Screw hoist	Yes	......	....	....	....
Rochester...	11	11	11	48	Jacks	......	......	....	....	....
Anderson...	16	16	16	33	Traveling electric hoists	......	......	....	Yes	Yes
Minneapolis	15	14	15	.....	Traveling electric cranes	Yes	Yes	Yes	Yes	Yes
Portland....	16	16	16	63	Jacks	......	Yes	Yes	Yes	Yes
Syracuse....	14	14	14	45	Hydraulic lift	Yes	......	Yes	Yes	Yes
Chicago....	15½	14	15½	25	Traveling electric cranes	Yes	......	Yes	Yes	Yes
Montreal...	16	16	16	39	....	Yes	......	....	Yes	Yes
Totals..	...	...	...	.....	....	7	3	5	8	8

story does not appear to be generally favored even in some of the shops located in congested city districts. Tracks which hold more than two cars are favored strongly for the erecting and paint shops, while opinion is about evenly divided for repair shops. The objection sometimes advanced to this arrangement, to the effect that it necessitates holding cars which may be finished before their turn, and also involves more complicated switching, therefore, does not appear to be considered seriously.

SECTION III

TRAIN MOVEMENT

Ton. Note that the ton of 2000 lb. (avoirdupois) is used throughout the book.

Schedules. In the preliminary determination of schedules for an electric railway the factors concerned bear directly on the amount of travel between various points and the time intervals during which such movements exist. Gotshall lists these factors and shows their relation to one another as follows:

P = number of people required to be carried
Q = time in hours during which business of P lasts
M = number of people one car will hold
S = schedule speed in miles per hour (including time for stops)
H = headway in minutes
D = length of line in miles
N = number of cars, if single cars be used, or train units, if more than one car be used
T = time in minutes occupied in running between terminals during one single trip

Then

$$\frac{P}{Q} = \text{number of people to be carried per hour}$$

$$\frac{P}{QM} = \text{number of cars required, which if single car trains be used} = N$$

$$\frac{D \times 60}{T} = \text{schedule speed in miles per hour} = S$$

The formula connecting N, S, D and H is

$$N = \frac{120 \times D}{S \times H}$$

which by transposition is

$$H = \frac{120 \times D}{S \times N} \text{ or } S = \frac{120 \times D}{H \times N}.$$

The foregoing, together with the knowledge of the probable amount of the heaviest business, will give at once the number of cars or train units by assuming the schedule speed and headway, or, if the number of train units be fixed in advance, by assuming the schedule speed, the required headway is at once shown.

Chart for Headway Calculations. If the schedule speed and any one of the following factors—headway in seconds, headway in feet, cars per mile—is given, the other factors may be obtained quickly by reference to the chart developed by Mr. H. M. Wheeler, Asst. Chief Engr., Chicago Railways Company (Electric Railway Journal, 1910). The chart is reproduced in Fig. 1. The curved line marked "cars per mile" is an hyperbola and shows the relation between cars per mile, read on the horizontal scale, and feet as shown on the vertical scale. The diagonal lines converging at the left and marked "distance between cars" show for various headways in seconds (at the bottom of the chart), the spacing of cars in feet, by the use of the diagonal line corresponding to the proper schedule speed.

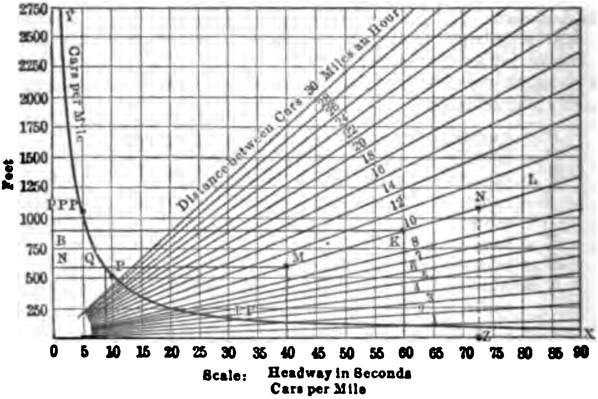


FIG. 1.—Headway chart.

Frequency of Stops. The following table (Standard Handbook) shows the usual frequency of stops as encountered in various classes of railway service:

Steam locomotive through service	1 stop in 100 miles
Steam locomotive local service	1 stop in 20 miles
Steam locomotive suburban service	1 stop per mile
Electric interurban express	1 stop in 10 miles
Electric interurban local	1 stop in 2 miles
Electric suburban	1 to 2 stops per mile
City elevated or rapid transit	2 to 3 stops per mile
City surface lines	5 to 10 stops per mile.

Duration of stops varies approximately as follows for different classes of railway service:

Through trains, steam	5 minutes
Local trains, steam	2 minutes
Interurban cars, electric	10 to 30 seconds
City rapid transit trains, electric	10 seconds
City surface cars, electric	7 seconds.

The rate at which passengers board and leave cars, together with other minor conditions, practically determines the length of service stops in electric railway practice. Figs. 2 and 3 show the results of an investigation made in various cities on this subject by Mr.

R. W. Harris (Trans. A.I.E.E., 1910) and show the movement of passengers boarding and leaving cars, respectively, the number of passengers boarding and leaving being plotted against the number of seconds required per passenger for various cities. It will be noted that practically identical curves were obtained by plotting data observed in Milwaukee on different days two months apart.

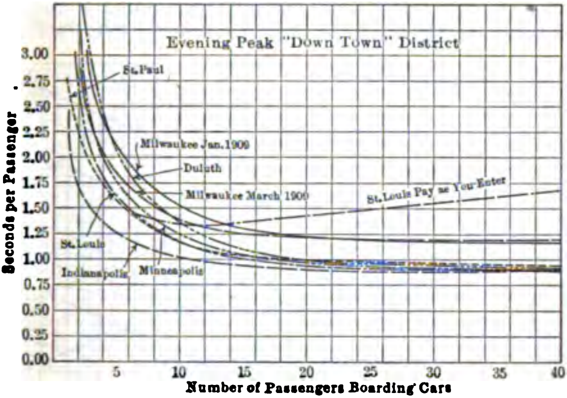


FIG. 2.—Movement of passengers boarding cars.

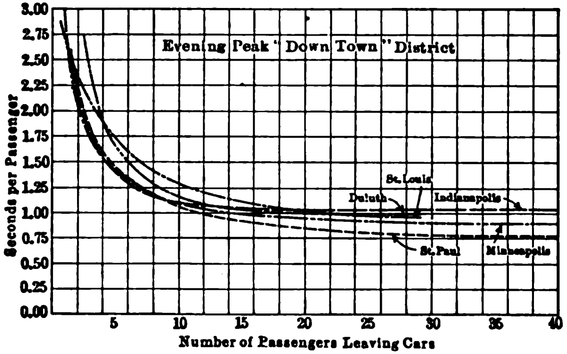


FIG. 3.—Movement of passengers leaving cars.

Graphical Train Schedules or Train Sheets. Many factors entering into the proper construction and successful operation of railways are at once apparent from the graphical train schedule which is plotted with time of day in hours and minutes against distances in feet or miles. It is convenient if the coordinate drawn through each hour division be made a heavy line on the coordinate paper and if these sections be subdivided into sixths or twelfths, representing 10- or 5-minute intervals, respectively. It is customary to designate the distance between stations in feet or miles, and the location of any points of special engineering interest, such as branch lines, railway crossings, city and township limits, etc. Sloping lines may then be drawn to represent the progress of a train from station to station, as shown in Fig. 4, reproduced from Harding's "Electric Railway Engineering." The inclination between these lines and the time axis depends upon and represents graphically the schedule speed of the train. A chart made up of such straight lines

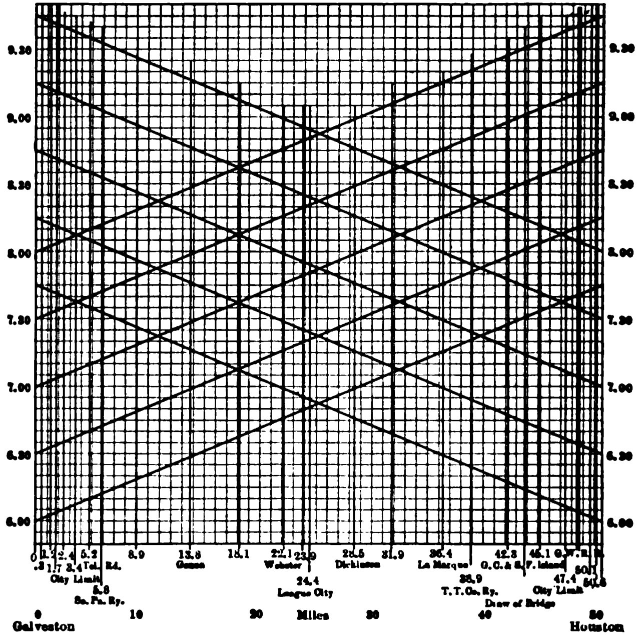


FIG. 4.—Preliminary interurban train schedule.

as shown in Fig. 4 is sufficiently accurate for a rough preliminary study of traffic possibilities, power requirements and substation locations, but before exact time tables can be adjusted and meeting points determined, a very much more accurate and detailed graphical train schedule must be drawn. Such a schedule involving several different schedule speeds over various sections of road as well as a representation of the time elapsed in making station stops is shown in Fig. 5. Such a graphical schedule enables the engineer to predetermine not only the number of cars necessary to maintain a given schedule and the position of all such cars at any moment, but it also locates the meeting points at the crossing of the schedule lines, and when used in conjunction with the power curves of the various cars, as described later, it aids in locating substations and determining the average and maximum loads on substations and power stations. Another illustration of the use of train sheets is shown in Fig. 6 from Gotshall's "Electric Railway Economics." In this case some of the details of the electrical distribution system are also shown. The particular schedules which have been illustrated are relatively simple ones. With the addition of express and local service and in some cases freight and mail trains, with the necessity of meeting the schedules of trunk and branch lines, a graphical schedule may become rather complicated, but by the use of a large scale drawing such solutions are made with little difficulty.

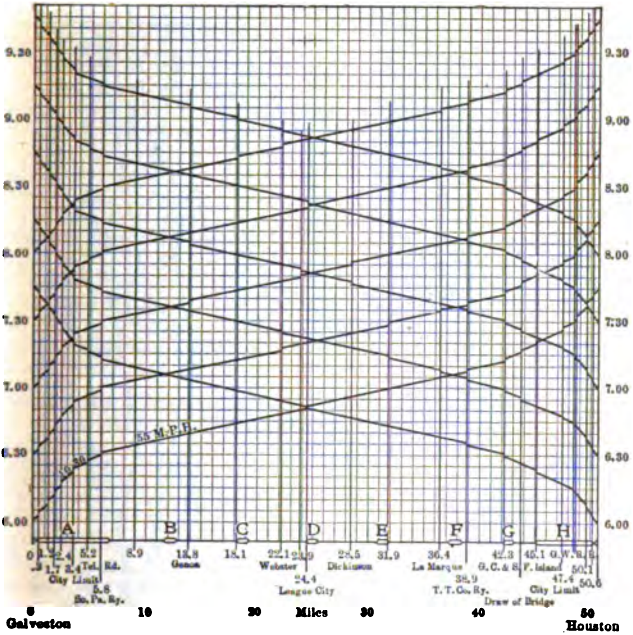


FIG. 5.—Final interurban train schedule.

Coefficient of Adhesion. As used in railway work the coefficient of adhesion is the coefficient of friction between driving-wheel tread and rail. It is equal to the ratio of the maximum possible tractive effort (neglecting torque limit of motor equipment) at the driving-wheel tread, to the normal pressure (called effective weight on driver) between rail and driving-wheel tread. It is usually expressed in per cent. of the effective weight on the driver. The

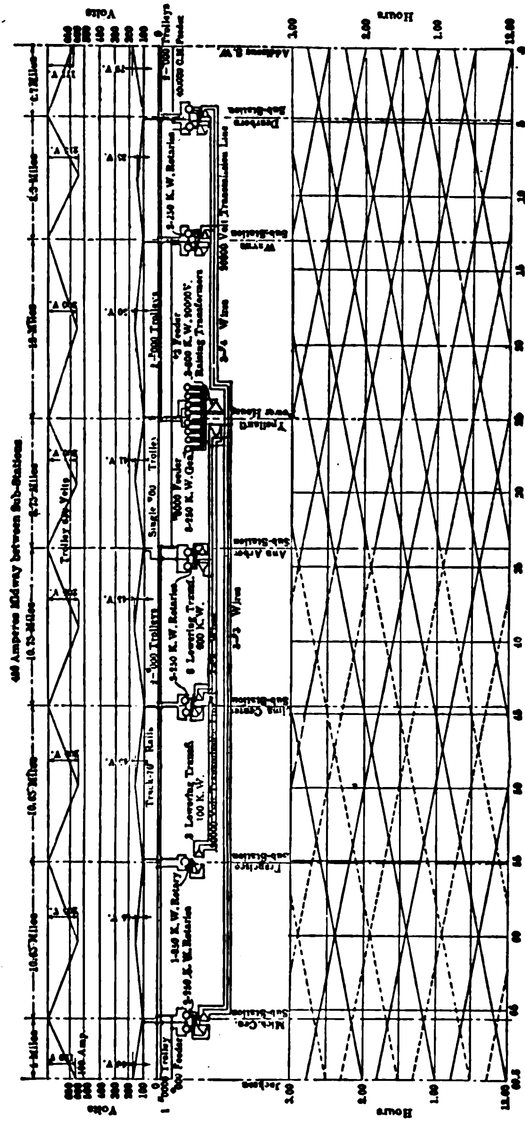


FIG. 6.—Train sheet and diagram of electrical distribution—Detroit, Ypsilanti, Ann Arbor & Jackson Railway.

results of tests to determine the coefficient of adhesion vary considerably. This variation is probably due to the difficulty in ascertaining, describing and duplicating the exact condition of rail and wheel surfaces.

It is common steam locomotive practice to assume 0.22 and 0.25 as the coefficient of adhesion with clean very dry rails. Because of torque uniformity throughout a revolution of a driving wheel higher maximum values are possible in electric railway practice, but in order to take full advantage of this fact all sudden fluctuations in torque such as might be brought about by improper arrangement of resistance taps or improper controller manipulation must be avoided.

Coefficient of adhesion is a quite variable quantity depending upon the condition of the rail and wheel. Neglecting the use of sand, a clean dry or very wet rail gives the highest coefficient of adhesion. Instances have been noted where the value of the coefficient of adhesion with a thoroughly wet rail has been nearly that for a perfectly dry rail, while with the presence of moisture in amounts scarcely perceptible to the unaided eye it has been found to be very low. Sand, while detrimental in its abrasive effect, improves poor adhesion and by its use very high values may be obtained with dry rail. It is, however, unsafe to depend upon sand to improve adhesion with dry rail because the sand is liable to be blown from in front of the wheel. When the wheels are slipping the coefficient of adhesion is the coefficient of kinetic friction between driving wheel tread and rail, and its value is less than 0.10.

Approximate Values of Coefficient of Adhesion (Without Slipping)

Clean dry rail	0.25 to 0.30;	with sand 0.35 to 0.40
Clean thoroughly wet rail	0.18 to 0.20;	with sand 0.22 to 0.25
Greasy and moist rail	0.15 to 0.18;	with sand 0.22 to 0.25
Sleet on rail	0.15	with sand 0.20
Light snow on rail	0.10	with sand 0.15

In the Electric Journal, 1910, Mr. H. L. Kirker notes a test on a Pennsylvania R. R. direct-current locomotive developing a drawbar pull of 79,200 lb. Since this locomotive has 200,000 lb. on the drivers this indicates a coefficient of adhesion of about 0.40.

Coefficients of Adhesion Used in Design. It is common practice to so design a locomotive that it will be able to slip its driving wheels with the best track conditions. The following table from weight and tractive effort data given by the Electric Journal, 1910, shows the coefficients of adhesion for maximum tractive effort used in the design of certain electric locomotives.

Locomotive	Wt. on drivers, lb.	Max. tractive effort, lb.	Coefficient of adhesion used in design
Grand Trunk & St. Clair Tunnel	132,000	43,000	0.33
N.Y.C. & H.R.R.R.	141,000	47,000	0.33
Detroit River Tunnel	200,000	67,000	0.33
B. & O. R. R.	184,000	61,000	0.33

The Electric Railway Journal, 1912, states that the maximum tractive effort measured at the driving-wheel treads of the single-phase locomotives for the Dessau-Bitterfeld line of the Prussian Hessian State Rys. is 15,400 lb. for the passenger locomotive and 26,400 lb. for the freight locomotive, which indicates a design coefficient of adhesion of about 0.21 for the passenger locomotive and 0.19 for the freight locomotive.

Grades: Actual, Ruling, Virtual

Actual Grade. The actual grade of a track is its rate of uniform rise or fall. It is equal to the difference in elevation between two adjacent points on the grade divided by the horizontal distance between them, *i.e.*, the tangent of the angle of inclination of the track to the horizontal. Grade is generally expressed in per cent.

Approximate Value of Grade. As it is easier to measure the distance along the track than along the horizontal, this substitution is often made. This introduces no serious error in the case of the small angles of inclination encountered in the usual railroad work as the sine thus substituted is practically equal to the tangent.

Average Grade. The average grade of a section of track connecting two given points is the ratio of the difference in elevation of these two points to their distance apart, measured in the same unit. It is usually expressed in per cent.

Ruling Grade. The ruling grade of a road or section of road is that grade which limits the weight and length of train to be propelled over that road or section by a given motive power. Its value is fixed by the traffic and economic conditions encountered on the particular section under consideration. The maximum weight of train to be propelled by a given motive power and limited by the ruling grade is that weight of train which the given motive power would cause to move up a continuous grade equal in per cent. to the ruling grade, at some predetermined constant speed. The grade of the greatest per cent. on a section need not always be the ruling grade for that section. The length of the grade, the rates of those grades preceding it, and the speed of the train on entering the grade are of as much importance as the rate of the grade, because a grade which may be approached at considerable speed by a given train may be easily passed over while a longer grade of much lower rate may be sufficient to stall the same train.

Momentum Grade. A grade whose operation is made possible by the momentum of a train which approaches the grade at a considerable velocity is called a momentum grade (or velocity grade). Grades of much greater rate than that of the ruling grade may be operated in this way in order to save the expense of their reduction. The argument against the very extensive use of the momentum grade is the possibility of some unforeseen condition such as the presence of a new crossing or a new stopping place which would so reduce the speed of the train that the momentum of the train would be insufficient to help it over the grade. The possibility that such a condition will arise to limit train movement is more remote on an old road where stopping places are fairly well established than it is on a new road in a rapidly growing community. This point is of importance in fixing the ruling grade for a new road or in reducing the rate on an old one. In some cases the necessity for reducing or removing a grade may be foreseen, but the time of its occurrence may be so remote that it will pay to delay this reduction or removal till the change is made necessary by developing conditions.

Virtual Profile. The electric railway engineer usually finds it convenient to study the relation of grades, trains and equipment together directly on the speed-time and distance-time curves (see Run Curves) for the train and equipment operating in the required direction on a typical run between whose limits lies the particular section under investigation. Unless the train is operated at constant speed (as by three-phase induction motors) care must be exercised that the speed of the train shall become neither dangerously high at the foot of a grade nor so low at the top of a grade that there is a probability that the train may be stalled by a strong head wind or adverse conditions of track, or both. As an aid in adjusting speeds, locating points where power should be cut off, brakes applied, or regeneration resorted to, or in studying the shortening or reduction of grades for the satisfactory operation of a given equipment and train weight over a given section, a virtual profile is sometimes plotted. The virtual profile depends upon the following six items: (1) actual profile of the section considered, (2) track curves in the section, (3) equipment (motors and gears), (4) train weight, (5) direction of motion on the given section, (6) known speed at the beginning of the section. It is only possible to construct a virtual profile for a section at whose beginning the speed of the train is zero or some other definitely known value.

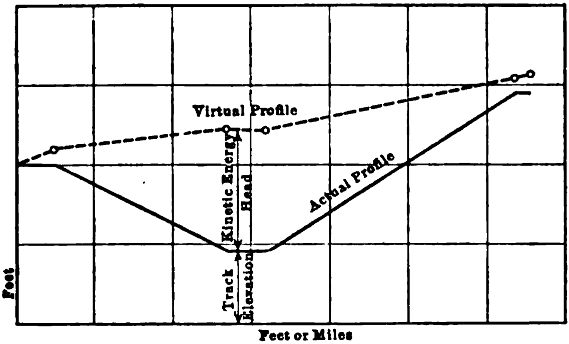


FIG. 7.—Sample virtual profile.

Construction of the Virtual Profile. To construct the virtual profile, the actual profile for the track section is first plotted with elevations as ordinates; then the virtual profile is the locus of all points, the ordinate of each of which is equal to the sum of the corresponding ordinate of the actual profile and the kinetic energy head (see below) (to the same scale) of the given equipment and train, when at the location on the track indicated by that point on the actual profile, and traveling in the direction considered. A virtual profile thus constructed will generally be curved. For most purposes, however, it is sufficient to plot only the points of the virtual profile corresponding to the ends of each grade (and curve) and connect the successive points thus plotted by straight lines (see Fig. 7).

General Properties of the Virtual Profile. The virtual profile for a given train and section of track touches the actual profile where the train is at rest, it diverges from the actual profile where the train is accelerating (velocity increasing), it is parallel to the actual profile where the velocity of the train is constant, and it converges toward the actual profile where the train is retarding. These properties are briefly summed up in the following table:

Train	Virtual profile relative to actual profile
Standing (zero velocity)	Touches
Accelerating (velocity increasing)	Diverges from
Constant velocity	Parallel to
Retarding	Converges toward

Kinetic Energy Head. The kinetic energy head (also known as the velocity head) for a train at any particular speed is the height to which the kinetic energy of the train at that speed would lift the train against the force of gravity alone. It is equal to the height through which the train acted on by the force of gravity alone would have to fall from rest to acquire a kinetic energy equal to that of the train at the particular velocity considered. With the falling mass there is no effect of rotating parts, therefore in order to acquire an amount of energy equal to that of the train at any instant a mass equal to that of the train and acted upon by the force of gravity alone must fall through a greater height than would be necessary in acquiring a speed equal to that of the train at that instant. The following derivation of the formula for kinetic energy head is further explanatory of the term.

At any instant $E = \frac{mv^2}{2k} = \frac{mv_1^2}{2}$

in which E = kinetic energy of train at speed V
m = mass of train
v = speed of train, feet per second
k = ratio of linear inertia to total inertia of train (see page 172)
v_1 = velocity of the falling mass m, feet per second

therefore

$v_1^2 = \frac{v^2}{k}$ which when substituted in $h = \frac{v_1^2}{2g}$ (for a body falling from rest) gives

$$h = \frac{v^2}{2gk} = \left(\frac{0.03342}{k}\right) V^2$$

in which h = kinetic energy head, feet
V = speed of train, miles per hour
k = same as above.

A convenient graphical solution of the last equation is given by Fig. 8.

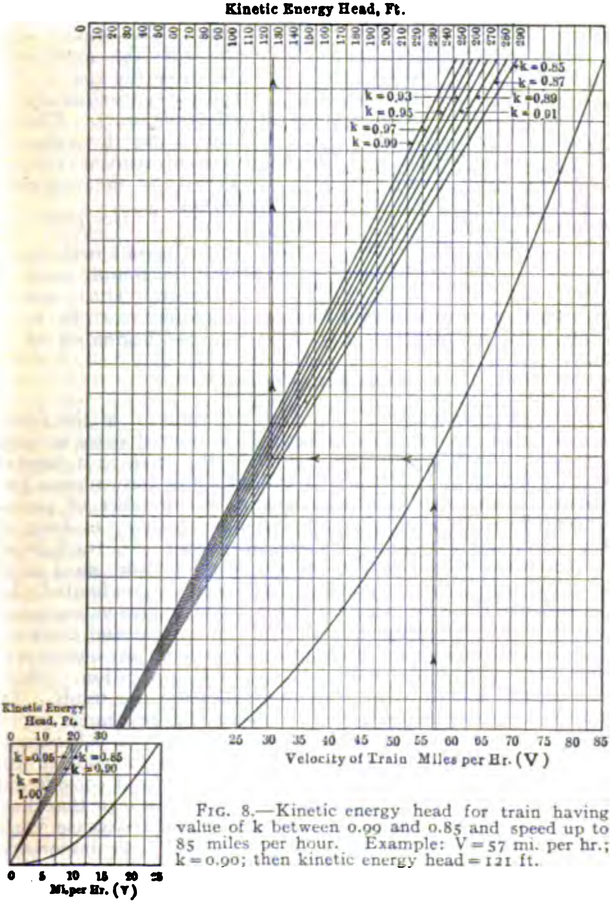


FIG. 8.—Kinetic energy head for train having value of k between 0.99 and 0.85 and speed up to 85 miles per hour. Example: V = 57 mi. per hr.; k = 0.90; then kinetic energy head = 121 ft.

Example of the Method of Locating a Single Point on a Virtual Profile: Suppose Fig. 9 gives the speed-time and distance-time curves for a train on a run containing a section of track for which, with the train operating in the direction considered, the virtual profile is desired. To find the velocity of the train at any given point, first determine how far this point is from the beginning of the run; for an example, let this be 0.45 mile. At the point representing 0.45 mile on the distance curve, erect a line perpendicular to the time axis. The point where this cuts the speed curve indicates the speed of the train (approximately 25 miles per hour). Allowing 0.90 to be the value of k and substituting this and $V = 25$ in the expression $\frac{0.03342}{k} V^2$ (see page 144), the value of kinetic energy head is found equal to 23.21 ft. The point on the virtual profile is finally located by adding 23.21 ft. to the elevation of the point at 0.45 mile from the beginning of the run.

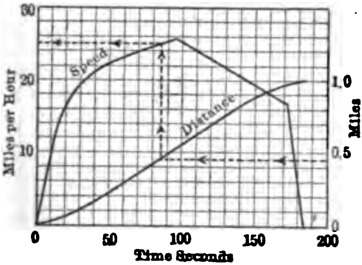


FIG. 9.

Train Resistance

Train resistance may be defined as the resultant of the forces, exclusive of those which are evidenced by internal losses in motor equipment, which oppose the motion of the train at a constant speed on a tangent level track in still air. For convenience train resistance at any speed is expressed as the number of pounds tractive effort at the driving wheel treads necessary to keep the train moving at that constant speed on tangent level track in still air. From the results of tests by many investigators most of the many train resistance formulas have been approximated, but while many of these formulas have been shown to give values nearly equal to those secured by test on certain equipment and track and under certain conditions, it is not safe to depend on any one formula to give very close approximations in universal application. This is because there are so many conditions affecting the result. The variation of some factors, such as temperature change in the bearings, may be comparatively slow, while that of others, such as of air resistance, may be great from moment to moment during the operation of the train. One of the points of considerable disagreement among the formulas for train resistance that have been devised is the manner in which the train resistance varies with the speed. At low speeds this is of but little importance compared with other factors, but at high speeds it becomes one of the most important factors in determining the speed for economic operation.

The more recent train resistance formulas recognize three principal ordinary components which are conveniently referred to as (1) journal friction, (2) rolling friction, and (3) air resistance.

Journal Friction. Journal friction of the car wheel axles has been found to depend upon the weight and speed of the train, and as the weight of the train increases the journal friction becomes of less importance per unit weight of train until it reaches a lower limiting value of about 3.5 lb. per ton weight of train. Lower values of journal friction have been secured in tests. The 1904 Proceedings of the Am. Ry. Eng. and Maint. of Way Assn. states that a coal car with 40 to 50 tons of coal will not have a journal friction of more than 2.5 lb. per ton, while the same car empty will have a journal friction of about 5 lb. per ton. As noted under "Temperature Effects on Train Resistance," the condition of the lubricant has a considerable effect on journal friction.

Rolling Friction. Rolling friction, including rail friction, increases with the speed of the train and depends upon the diameter of the wheels, general design of the truck and the condition of wheels and track. It is greater as the wheel and rail surfaces are more imperfect and increases with track irregularity and flexibility. Track irregularity and flexibility are also important in setting up oscillations and concussions, the damping of which consumes energy. In this process flange friction is also increased. All of these effects are so closely related that for ordinary work it is impracticable to separate them.

Air Resistance. Tests to determine the value of air resistance have yielded the most widely differing results. Its value depends upon the speed of the train, the area of cross-section and lateral area of the locomotive and each car, the shapes of the front and rear ends of the train, and the number of cars composing the train.

Effect of Individual Car Weight on Train Resistance. Train resistance has been found to depend upon the weights of individual cars making up the train, that is to say, given two trains of the same total weight but made up of a different number of cars, the train resistance will be different for the two. Tests indicate that the train of heavier cars will have the lesser train resistance, and that this difference is not entirely due to different air resistance. (See Journal Friction, above, also Fig. 31 and Train Resistance of Freight Train, p. 161.)

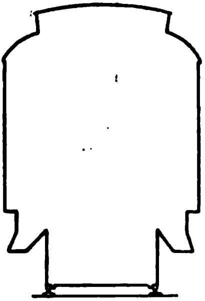


FIG. 10.—Outline of projected area considered in air resistance calculation.

Train Resistance Formulas. Of the many existing train resistance formulas, the following are a few in common use in making approximations:

Significance of symbols (special symbols are explained with the formulas in which they occur):

f = train resistance, pounds per ton weight of train

S = speed of train, miles per hour

W = total weight of train, tons

n = number of cars in train

a, a_1, a_2, a_3, a_4, etc. = area of cross-section of each car in train, square feet. This is equal to the area included within the outline of the projection of the car body, car wheels and horizontal line tangent to the heads of the rails on a plane perpendicular to the center line of the track (see Fig. 10).

W. J. Davis. (From data given in Street Railway Journal, 1902 and 1904.) The following formulas are by Mr. W. J. Davis from tests by him on the Buffalo and Lockport Railway and other data secured by him.

Significance of symbols:

b = constant component of journal friction, pounds per ton weight of train
= 3.5 for heavy loaded freight cars
= 4 for standard passenger coaches or large interurban cars
= 5 to 6 for light (city) cars with grease lubrication
c = combined coefficient of variable component of journal friction and rolling friction, pounds per ton weight of train per mile per hour
= 0.11 for heavy track construction
= 0.13 for medium track construction
d = air resistance coefficient, pounds per unit of squared velocity [(miles per hour)^2] per square foot of projected area of cross-section. (See a, etc., above and Wind Pressure, p. 166.)

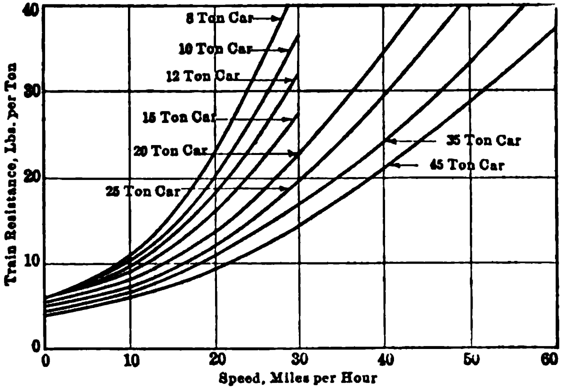


Fig. 11.—Train resistance, single car (Davis formula).

= 0.0035 for open platform cars
= 0.0024 to 0.0030 for vestibuled cars
m = coefficient of lateral windage, ratio of lateral wind resistance to combined head and rear air resistance of train
= 0.10.
(Other symbols as on page 147.)

Davis Formulas. With cars of various areas of cross-section,

$$f = b + cS + \frac{dS^2}{W}[a_1 + m(a_2 + a_3 + a_4 + \text{etc.})]$$

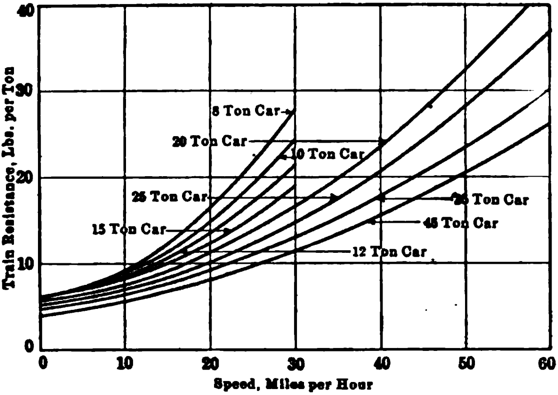


FIG. 12.—Train resistance, two-car train (Davis formula).

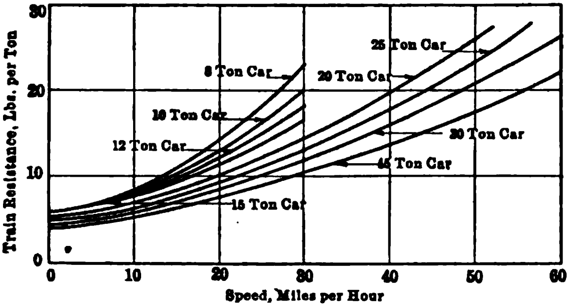


FIG. 13.—Train resistance, three-car train (Davis formula).

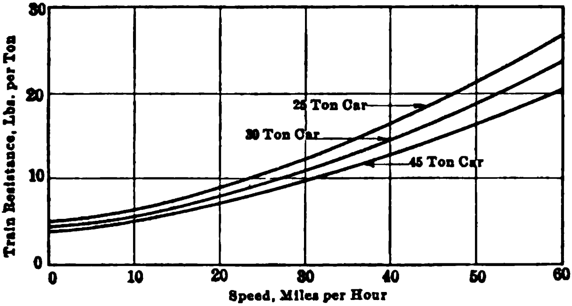


FIG. 14.—Train resistance, four-car train (Davis formula).

With cars having equal areas of cross-section,

$$f = b + cS + \frac{daS^2}{W}[1 + m(n - 1)]$$

Application of the W. J. Davis formulas and coefficients. Figs. 11 to 16 inclusive give graphical solutions of train resistance problems according to the W. J. Davis formulas. Following are the corresponding formulas:

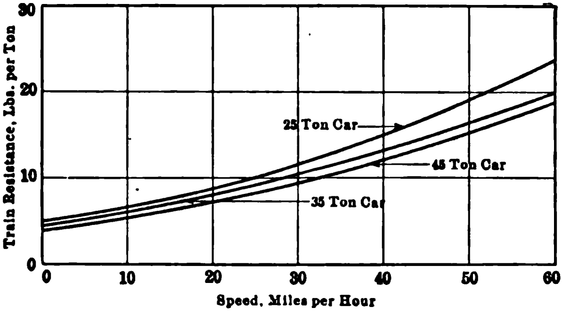


FIG. 15.—Train resistance, six-car train (Davis formula).

Open Platform City Cars. Weight, 8 tons to 20 tons; area of cross-section, 85 sq. ft.; max. speed, 30 miles per hour:

$$f = 6 + 0.11\,S + \frac{0.3S^2}{W}[1 + 0.1\,(n - 1)]$$

Interurban cars. Weight, 25 tons to 40 tons; area of cross-section, 100 sq. ft.; maximum speed, 60 miles per hour:

$$f = 5 + 0.13\,S + \frac{0.3S^2}{W}[1 + 0.1\,(n - 1)]$$

Heavy Interurban Cars, or Steam Passenger Coaches. Weight, 40 tons to 50 tons; area of cross-section, 110 sq. ft.; maximum speed, 75 miles per hour:

$$f = 4 + 0.13\,S + \frac{0.33S^2}{W}[1 + 0.1\,(n - 1)]$$

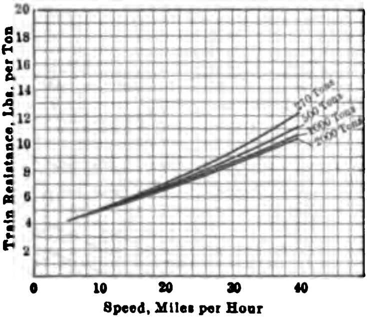


FIG. 16.—Freight train resistance (Davis formula).

Freight Trains. Weight of each car, 45 tons loaded; area of cross-section, 110 sq. ft.; maximum speed, 35 miles per hour:

$$f = 3.5 + 0.13\,S + \frac{0.385\,S^2}{W}[1 + 0.1(n - 1)]$$ (See also Figs. 15 and 16.)

University of Illinois (Single Car). (From Bulletin No. 74, by Mr. Harold H. Dunn, University of Illinois, 1914.) The following formula was developed from the results of tests with a 45-ft., 28-ton interurban electric car:

$$f = 4 + 0.222\,S + \frac{0.00181\,aS^2}{W}$$

A. H. Armstrong. The following train resistance formula by Mr. A. H. Armstrong, Standard Handbook, is based on data secured from many tests.

$$f = b + cS + \frac{dS^2a\,[1 + 0.1\,(n - 1)]}{W}$$

in which b = constant component of journal friction, pounds per ton weight of train

= $\frac{50}{\sqrt{W}}$ but having a limiting minimum value of 3.5. (For graphical solution see Fig. 17)

c = combined coefficient of variable component of journal friction and rolling friction, pounds per ton weight of train per mile per hour

= from 0.03 to 0.07. 0.03 for ordinary conditions and car weight. Higher values for poor track conditions and car weighing less than 35 tons. (For graphical solution of cS see Fig. 18)

d = air resistance coefficient. Varies from 0.004 for perfectly flat ends (no vestibule) to 0.0015 with pointed ends of extreme type

= approximately 0.002 to 0.0025 for rounded end suburban car and electric locomotive with sloping front. (For graphical solution of $\frac{dS^2a\,[1 + 0.1\,(n - 1)]}{W}$ see Figs. 19 and 20.)

(Other symbols as on page 147.)

Application of the A. H. Armstrong Formula and Coefficients. Figs. 21 to 25 give graphical solutions of train resistance problems for particular equipments according to the A. H. Armstrong formula and coefficients. The values assumed for end cross-section in the construction of Figs. 21 to 25, inclusive, are as follows:

88 sq. ft.	for 20-ton car
93 sq. ft.	for 25-ton car
100 sq. ft.	for 30-ton car
113 sq. ft.	for 40-ton car
120 sq. ft.	for 50-ton car
120 sq. ft.	for 60-ton car

A general solution is further afforded by the use of Figs. 17, 18, 19 and 20, the approximate value of train resistance of any train being equal to the sum of the results obtained from Figs. 17, 18, and 19 or 20 (19 is to be used for speeds up to 35 miles per hour and 20 for speeds between 35 and 70 miles per hour).

John Balch Blood. (From paper before A.S.M.E., 1903.)

$$f = E + BS + (C + \frac{D}{W})S^{1.8}$$

in which E = coefficient of sliding friction
= 7 for light electric cars
= 6 for medium weight electric cars
= 5 for heavy electric cars
= 4 for average passenger trains
= 3 for heavy freight trains
B = coefficient of rolling friction
= 0.15 for light track construction
= 0.12 for heavy track construction
C = coefficient of side resistance
= 0.0016 for ordinarily constructed cars
= 0.0014 for cars with vestibules
D = coefficient of head and stern resistances
= 0.25 for cars of small cross-section
= 0.30 for electric cars of medium cross-section
= 0.35 for large electric or suburban trains
= 0.40 for largest express trains.
(Other symbols as on page 147.)

Dr. John Lundie. (From discussion by Dr. John Lundie, Street Railway Journal, 1902.)

Using the data secured from tests on the South Side Elevated Railroad, Chicago, and from many others, Dr. Lundie developed the following formula which he stated that he knew from experience to give correct results when applied to trains weighing from 20 tons to 100 tons, and traveling at speeds up to 30 miles per hour. He further stated that the formula conforms to results obtained on heavy trains at speeds as high as 60 miles per hour.

$$f = 4 + S\left(0.24 + \frac{4.8}{W}\right)$$

Other Train Resistance Formulas. Other train resistance formulas, which have been proposed from time to time, follow: (Symbols, as on page 147.)

W. N. Smith. $f = 3 + 0.167S + 0.0025\frac{a}{W}S^2$

Mailloux. $f = 3.5 + 0.150\,S + \frac{(0.02n + 0.25)S^2}{W}$

Sprague. $f = 4.0 + 0.160\,S + \frac{0.333\,S^2}{W}$

Berlin Zossen. $f = 4 + 0.02\,S + 0.0027\,S^2$

Clark. $f = 7.14 + \frac{S^2}{166}$

Rankine. $f = 2.65 + 0.27\,S$

Searles. $f = 4.82 + 0.005\,S^2 + \frac{0.6S^2}{W}$

Welkner. $f = 6.25 + 0.004\,S^2$

Wellington. $f = 4 + 0.005\,S^2 + \frac{(0.28 + 0.03n)S^2}{W}$

ENGINEERING NEWS. $f = 2 + \frac{S}{4}$

DODD. $f = 7 + \frac{S}{5}$

BALDWIN LOCOMOTIVE WORKS. $f = 3 + \frac{S}{6}$

GOTSHALL. $f = (\frac{D}{\sqrt{W}} + g) + 0.15\, S + \frac{(0.02n + 0.25)}{W} S^2$

in which D = constant depending on the diameter of car wheels and journals
= between 6 and 9
g = constant depending upon condition of track
= from 2 to 5.

EASTERN RY. OF FRANCE. Assuming constant area of cross-section = 90 sq. ft. for

(7.5 to 20 miles per hour) $f = 3.3 + 0.161S$

(20 to 31 miles per hour) $f = 3.6 + 0.258S + 0.259 \frac{S^2}{W}$

(31 to 40 miles per hour) $f = 3.6 + 0.258S + 0.173 \frac{S^2}{W}$

(43 to 50 miles per hour) $f = 3.6 + 0.451S + 115 \frac{S^2}{W}$

Comparison of Formulas by Application. Single-car train, 40-ton car; area of cross-section, 110 sq. ft. Fig. 26 gives the value of train resistance at speeds up to 75 miles per hour according to several of the formulas cited above.

Fig. 27 gives a comparison of the application of several train resistance formulas in the calculation of train resistance of the car with which the experiments, from which the University of Illinois formula was developed, were carried out.

Five-car train, 40-ton cars; area of cross-section, 110 sq. ft. Fig. 28 gives values over the same range when calculated according to the same formulas as used in constructing Fig. 26. This car had a cross-section of 90 sq. ft. and weighed 28 tons.

Train Resistance of Express Passenger Train. The following table of train resistance is from an article by Mr. A. M. Wellington, Engineering News, 1892. The train was the Empire State Express consisting of four loaded passenger coaches, steam locomotive and tender; train weighing approximately 270 tons complete. The runs were made on the New York Central and Hudson River Railroad between New York and Albany over track which was practically level (having a few slight grades, generally of 0.1 per cent.). The tests were made by means of the steam engine indicator, and then an efficiency of 95 per cent. was allowed for the transmission of energy to the wheel treads. The values given in the table are plotted in Fig. 29 and a curve is shown for comparison with curves constructed on the Armstrong, Davis (for steam passenger coaches), Engineering News, and Baldwin Locomotive Works formulas.

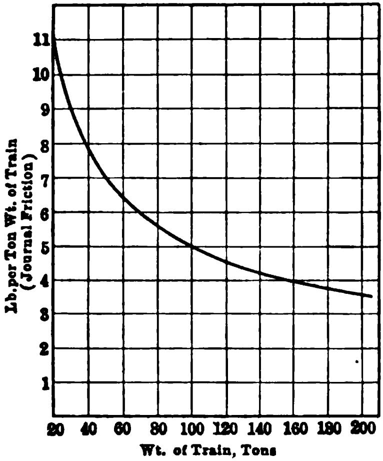


Fig. 17.—Constant component of journal friction in train resistance (Armstrong formula).

The values assumed are: area of cross-section 110 sq. ft. and wind pressure coefficient 0.0035. The variation of the plotted test values indicate the difficulty in obtaining consistent train resistance tests.

Speed of train, miles per hour	Train resistance, pounds per ton weight of train
37.1	21.3
44.0	16.5
58.0	20.2
60.0	21.1
60.8	15.8
68.6	18.7
69.0	18.8
69.6	19.8
70.5	18.2
70.5	19.8
71.9	18.9
78.9	18.8

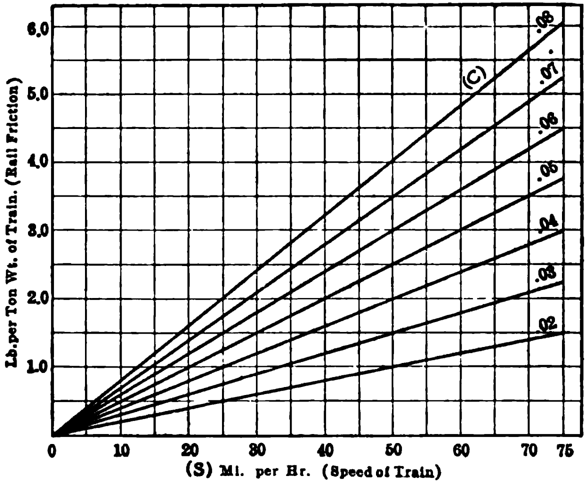
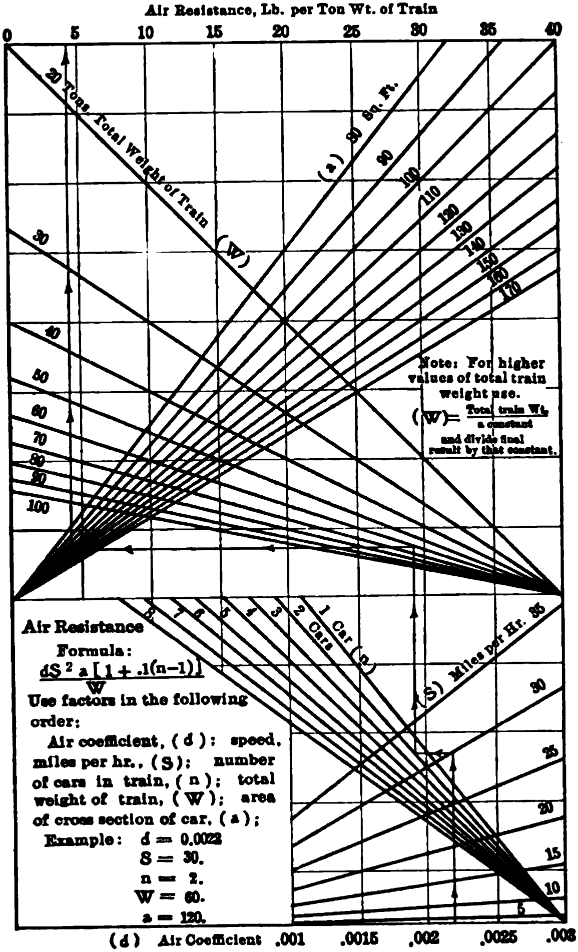


Fig. 18.—Rolling friction plus variable component of journal friction in train resistance (Armstrong formula).



Note: For higher values of total train weight use.

$(W) = \frac{\text{Total train Wt.}}{\text{a constant}}$

and divide final result by that constant.

Air Resistance

Formula:

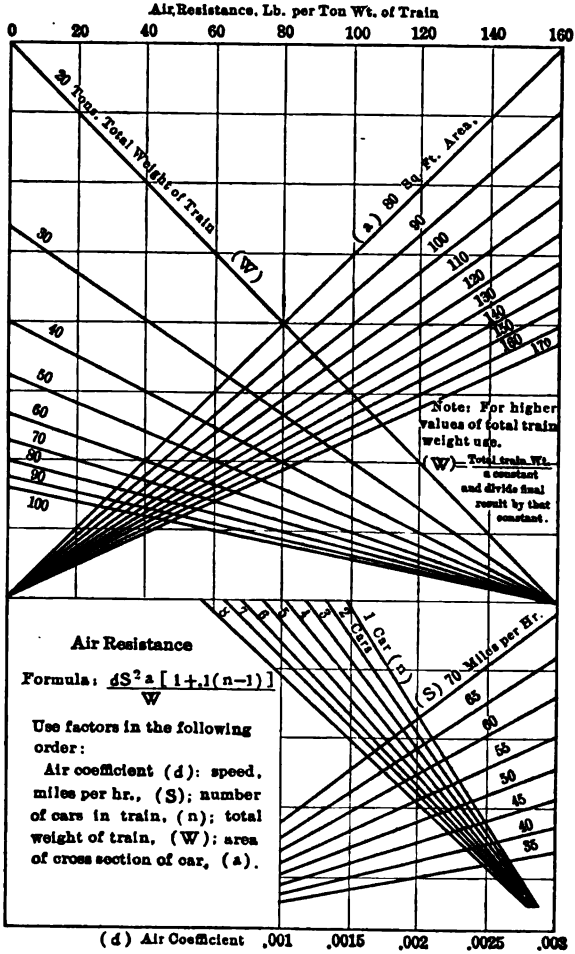
$$\frac{dS^2 a[1 + .1(n-1)]}{W}$$

Use factors in the following order:

Air coefficient, (d): speed, miles per hr., (S): number of cars in train, (n): total weight of train, (W); area of cross section of car, (a);

Example: d = 0.0022
S = 30.
n = 2.
W = 60.
a = 120.

FIG. 19.—Air resistance component in train resistance to 35 miles per hr. (Armstrong formula).



Note: For higher values of total train weight use.

$(W) = \frac{\text{Total train Wt.}}{\text{a constant}}$ and divide final result by that constant.

Air Resistance

Formula: $\frac{dS^2a\,[1 + .1(n-1)]}{W}$

Use factors in the following order:

Air coefficient (d): speed, miles per hr., (S); number of cars in train, (n); total weight of train, (W); area of cross section of car, (a).

FIG. 20.—Air resistance component in train resistance, 35 to 70 miles per hr. (Armstrong formula).

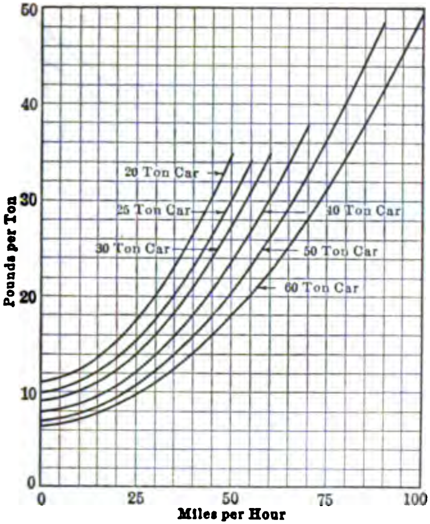


Fig. 21.—Train resistance, single car (Armstrong formula).

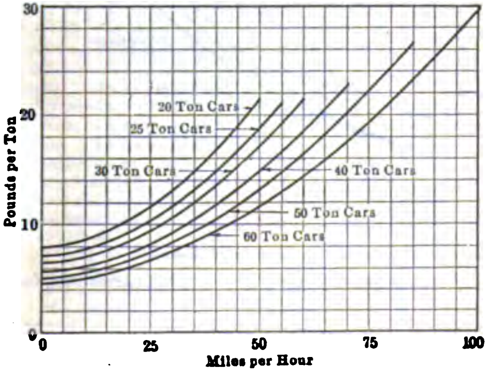


Fig. 22.—Train resistance, two-car train (Armstrong formula).

Comparison of Train Resistance Values Secured in Illinois Central Tests with Values Obtained by Formulas. Fig. 30 shows train resistance for three 1350-ton freight trains made up of cars having average weights of 30 tons, 45 tons and 75 tons, respectively. The curves showing the values obtained from the Illinois Central

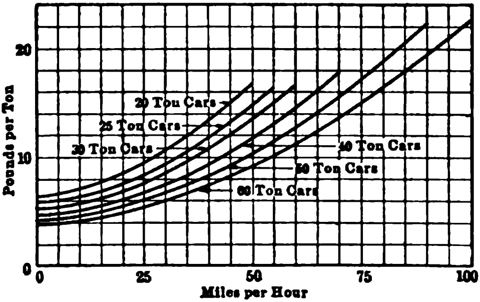


FIG. 23.—Train resistance, three-car train (Armstrong formula).

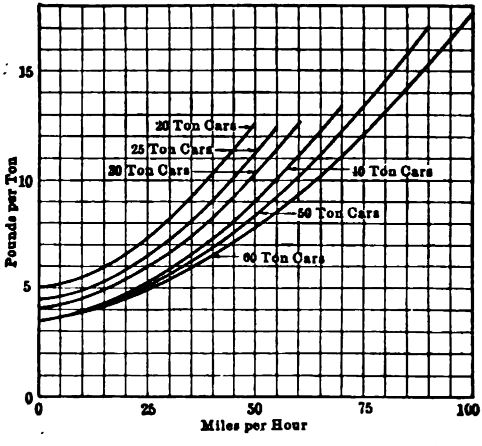


FIG. 24.—Train resistance, five-car train (Armstrong formula).

tests were taken directly from Fig. 31. One curve for each train was constructed on the Armstrong formula, and one curve for each train was constructed on the Davis formula for freight trains. One curve was constructed on each the Engineering News and Baldwin Locomotive Works formulas (neither of these formulas gives consideration to train weight, therefore but one curve is necessary for each). The effective area of cross-section was assumed to be 110 sq. ft. and the air resistance coefficient for front and rear was taken as 0.0035. Since the test curves were constructed on values

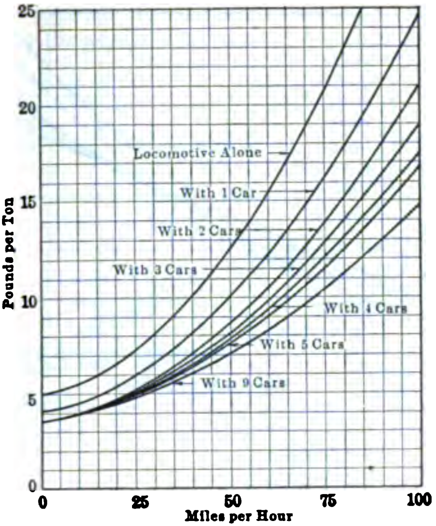


FIG. 25.—Train resistance, locomotive and train (Armstrong formula).

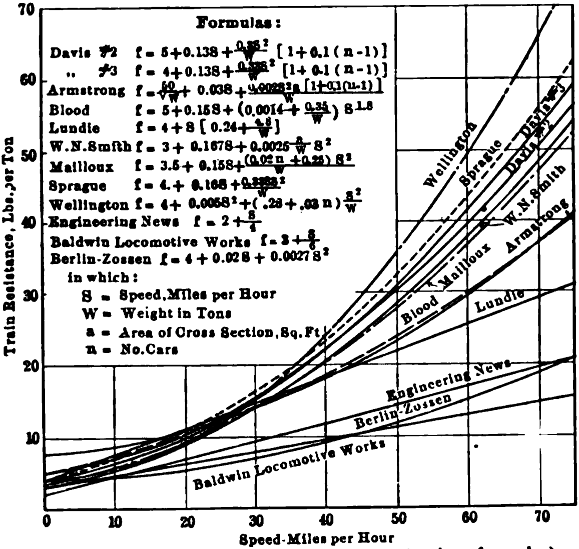


FIG. 26.—Train resistance, single 40-ton car (various formulas).

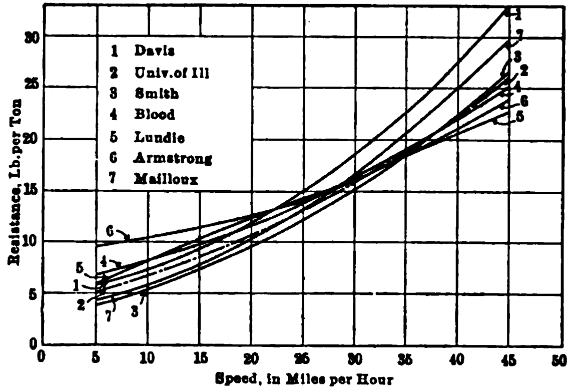


FIG. 27.—Train resistance, single 28-ton car (various formulas).

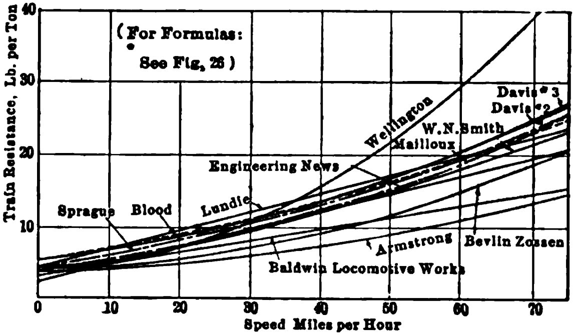


FIG. 28.—Train resistance, five-car train (various formulas).

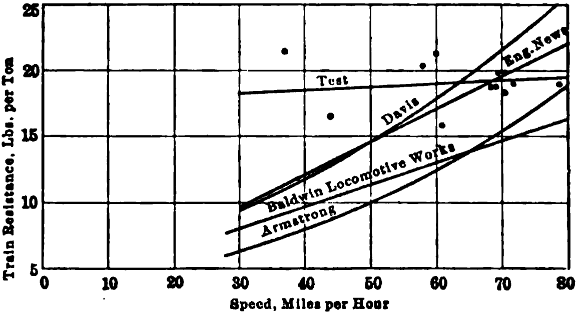


FIG. 29.—Train resistance, steam locomotive and train (various formulas and test).

obtained at the draw bar, the values obtained by the formulas were each reduced by the amount $0.000244S^2$ (S being the speed of the train, miles per hour) for the front air resistance which is not included in the results obtained at the draw bar. At 40 miles per hour this correction amounts to 0.39 lb. per ton weight of train.

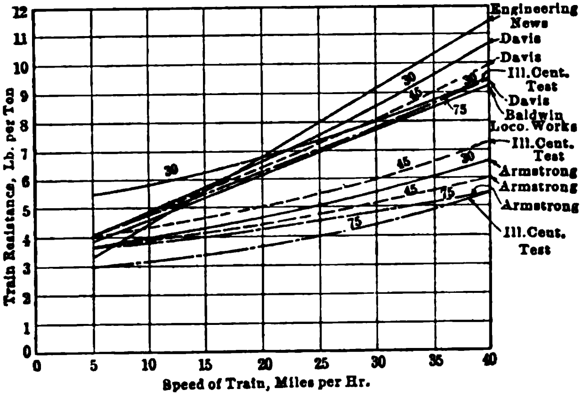


FIG. 30.—Train resistance, freight trains (various formulas and tests).

Train Resistance of Freight Train. Fig. 31 taken from Bulletin No. 43 by Prof. Edward C. Schmidt of the University of Illinois Engineering Experiment Station gives values of train resistance for freight trains of various average weights per car. The following formulas by the same authority are empirical, yielding values whose maximum variation from those given by Fig. 31 is 0.5 per cent. when used within the speed limits of Fig. 31.

TRAIN RESISTANCE FORMULAS

When $W = 15$ tons; $f = 7.15 + 0.085\ S + 0.00175\ S^2$
$W = 20$ tons; $f = 6.30 + 0.087\ S + 0.00126\ S^2$
$W = 25$ tons; $f = 5.60 + 0.077\ S + 0.00116\ S^2$

$W = 30$ tons; $f = 5.02 + 0.066\ S + 0.00116\ S^2$
$W = 35$ tons; $f = 4.49 + 0.060\ S + 0.00108\ S^2$
$W = 40$ tons; $f = 4.15 + 0.041\ S + 0.00134\ S^2$

$W = 45$ tons; $f = 3.82 + 0.031\ S + 0.00140\ S^2$
$W = 50$ tons; $f = 3.56 + 0.024\ S + 0.00140\ S^2$
$W = 55$ tons; $f = 3.38 + 0.016\ S + 0.00142\ S^2$

$W = 60$ tons; $f = 3.19 + 0.016\ S + 0.00132\ S^2$
$W = 65$ tons; $f = 3.06 + 0.014\ S + 0.00130\ S^2$
$W = 70$ tons; $f = 2.92 + 0.021\ S + 0.00111\ S^2$
$W = 75$ tons; $f = 2.87 + 0.019\ S + 0.00113\ S^2$

The following formula gives an approximation to the values of train resistance given by Fig. 31 (the maximum difference being 9.5 per cent. which occurs at $S = 21$ and $W = 55$).

$$f = \frac{S + 39.6 - 0.031W}{4.08 + 0.152W}$$

11

in which f = train resistance, pounds per ton
W = weight of car, tons
S = speed of train, miles per hour.

These curves (Fig. 31) may be applied to predict the probable total train resistance of entire freight trains which are either homogeneous or mixed as regards individual car weights and which have been in motion for some time, when the air temperature is above 30 deg. F. and the velocity of the wind is not more than 20 miles per hour. Due to variation in make-up or external conditions, some trains may have a train resistance about 9 per cent. in excess of that given by Fig. 31, but this is of importance only in rating the motive power for speeds under 15 miles per hour.

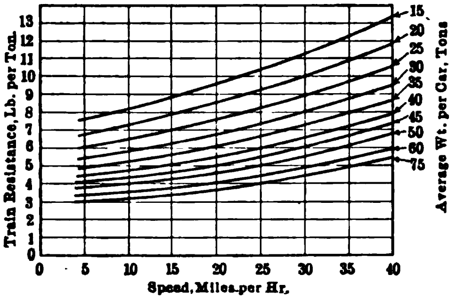


FIG. 31.—Freight train resistance (Univ. of Ill. formula).

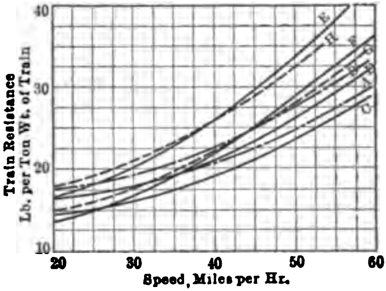
The above results were obtained from tests of thirty-two ordinary freight trains in regular service of such make-up as naturally resulted from the traffic conditions in the Champaign yards of the Illinois Central Railroad. The chief characteristics of these trains were as follows:

	Minimum	Maximum
Total weight of train, tons	747.00	2908.00
Average weight of cars composing the train, tons	16.12	69.92
Number of cars in the train	26.00	89.00
Train length, feet	1120.00	3480.00

The trains whose average car weights were less than 20 tons or more than 60 tons were composed of cars of nearly uniform weight; while those whose average car weights were between 20 and 60 tons were either homogeneous or mixed as regards the weights of the individual cars. Presumably, the majority of the cars had journals conforming to the specifications of the Master Car Builders' Association which for some years have required that the size of freight car journals be either 3¾ by 7 in., 4¼ by 8 in., 5 by 9 in., or 5½ by 10 in., depending upon the car capacity. All the cars had four wheel trucks and it is safe to assume that all the car wheels were 33 in. in diameter.

The track on which these tests were made is on the Chicago division of the main line of the Illinois Central Railroad. It extends from Gilman to Mattoon, Ill., a distance of 91 miles. The maximum grade against north-bound traffic was 29 ft. per mile, and against south-bound traffic, 31.9 ft. per mile, and in the 91 miles there was 7850 ft. of curved track. The track was well constructed and well maintained, and probably was such as one might expect to find on main lines of first class railroads. About 94 per cent. of the track was of 85-lb. A.S.C.E. section rails put down in about 1900, and the remainder was of 75-lb. A.S.C.E. section rails put down in 1894 and 1895. It was laid on oak ties spaced 20 in. center to center. About 83 of the 91 miles was ballasted with broken limestone and the rest, which was in station grounds, was ballasted with screenings or cinders.

The purpose of the tests was to determine the train resistance of freight trains in usual operation and at the same time to determine, if possible, a relation between average car weight and train resistance at any given speed. None of the data used in the construction of the curves was taken before the train had been in motion at least 10 miles. The speed during the tests ranged from 5 to 35 miles per hour, the air temperature from 34 deg. F. to 82 deg. F. and the approximate average wind velocity during all but one test was less than 20 miles per hour. The direction of the wind relative to that of the track varied through 360 deg. during the tests. Each train resistance was reduced to train resistance on level track by correcting for grade. The tests were made by means of a dynamometer car and only take into consideration the train resistance of the part of the train behind the locomotive tender.



Curve	Front vestibule	Rear vestibule
A	Parabolic wedge	Standard
B	Standard	Parabolic wedge
C	Parabolic	Standard
D	Standard	Parabolic
E	Flat	Standard
F	Standard	Flat
G	Standard	None
H	None	Standard

FIG. 32.—Train resistance with various shapes of vestibules (El. Ry. Test Commission).

Relation Between Vestibule Shapes and Train Resistance. Fig. 32 gives approximate speed train-resistance curves for a single interurban car when tested with vestibules of various shapes at speeds up to 60 miles per hour. These curves are from data given in the report of the Electric Railway Test Commission, 1904, and according to that report they show what train resistance may be expected under ordinary conditions of service on a level track, especially the variation in train resistance due to various shapes of car ends. The tests on which these curves are based were performed with a dynamometer car which was operated on a tangent track of 70-lb. T-rails laid on gravel-ballasted oak ties. The general method of making the tests was to make determinations of speed, electromotive force applied to the car and current taken by the car while running at a practically constant speed. From the average values of electromotive force and current and the current-efficiency curve for the motor equipment the power required to balance train resistance at that speed was determined.

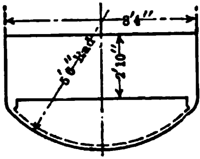


FIG. 33.—Standard vestibule (see Fig. 32).

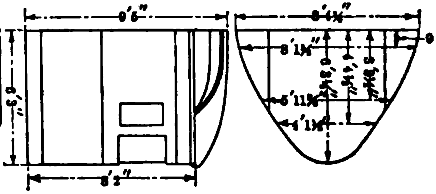


FIG. 34.—Parabolic vestibule (see Fig. 32).

The dynamometer car body was of an interurban type 32 ft. long without vestibules, the foundation was a pressed steel flat car of 100,000 lb. capacity, the trucks were Baldwin locomotive, M. C. B. interurban type with Gibbs cradle suspension, the motors were four Westinghouse No. 85, the gear ratio was 27 : 47. The total weight of the car was approximately 38 tons. The types of vestibules used consisted of a "standard," "parabolic," "parabolic wedge" and "flat." The dimensions of these are shown by Figs. 33, 34, 35 and 36, respectively.

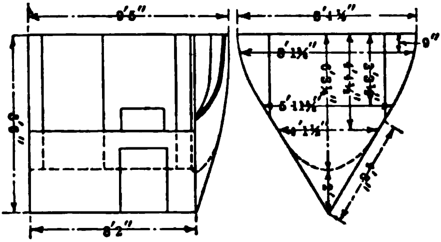


FIG. 35.—Parabolic wedge vestibule (see Fig. 32).

Wind Pressure. Wind pressure on a body varies with the velocity of the wind and the shape of the body presented to the wind. For convenience it is given in pounds per square foot of area projected on a plane perpendicular to the direction of the wind. (Wind used in this connection indicates relative motion of air and a body in the air.) The following formula has been found to show wind pressures agreeing with experimental results:

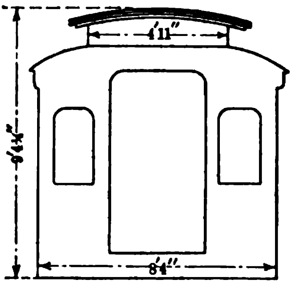


FIG. 36.—Cross-section of car (see Fig. 32).

$$P = dV^2$$

in which P = pressure on a plane surface normal to the direction of the wind, pounds per square foot

V = actual velocity of the wind, miles per hour. (See Wind Velocity below.)
d = wind coefficient. (See below.)

Wind Velocity. When wind velocity is tested by hemispherical cup anemometer

$$V = \log^{-1}[0.509 + 0.9012 \log v]$$

in which V = true wind velocity
v = actual velocity of cup centers.

Velocity given out by the Weather Bureau is obtained on the assumption that

$$V = 3v.$$

This gives a velocity higher than the actual velocity. By the following table the true wind velocity may be obtained from the velocity given out by the Weather Bureau:

Reported velocity	True velocity
10	9.6
20	17.8
30	25.7
40	33.3
50	40.8
60	48.0
70	55.2
80	62.2
90	69.2
100	76.2

Wind Coefficient for Plane Surface Normal to the Direction of the Wind. Following are values of wind coefficient determined by various methods:

Authority	Wind coefficient (d)
Weather Bureau	0.004
W. J. Davis	0.004
Martin	0.004
Longley	0.0036
Smeaton	0.005

The value of 0.004 is probably the closest approximation.

Wind Pressure on Other than Plane Surfaces. (From a paper by Professor Kernot before the Australasian Association for the Advancement of Science, 1893.) The following determinations were made by placing small models in an approximately steady jet of 10 in. by 12 in. cross-section.

Modulus. At any given wind velocity, the ratio of the wind pressure on a given body to the pressure on a plane surface normal to the direction of the wind and having an area of cross-section equal to the area of projection of the body on a plane normal to the direction of the wind is, for convenience, called the *modulus.*

Cube. The pressure on a cube was as nearly as possible the same whether the direction of the wind was parallel to a side or a diagonal and was 0.9 the pressure on a square card equal in size to a face of the cube.

Rectangular Blocks. x = length measured in the direction of the wind, y and z = dimensions in other directions.

Where $x = 2y = 2z$ .... modulus = 0.8
Where $x = 3y = 3z$ .... modulus = 0.7
Where $y = 2x = 2z$ .... modulus = 0.9
Where $y = 3x = 3z$ .... modulus = 0.9

A block representing a tower and having a height equal to three times its width of base gave a modulus of 0.9 when the direction of the wind was normal to one face. When the direction of the wind was the same as that of a diagonal the effect was, as nearly as could be measured, the same.

Pyramid. A pyramid of square base, having a height equal to about three times its base gave a modulus of 0.8 when a side was presented to the wind. When one angle was presented to the wind the total pressure was increased by 25 per cent.

Cylinder. Cylinders having the elements of their curved surfaces normal to the direction of the wind gave a modulus of 0.52.

Octagonal Prism. The pressure on an octagonal prism was 10 per cent. greater than on the circumscribing cylinder.

Cone. For a cone having a height equal to three times the diameter of the base, the modulus was 0.50.

Sphere. For a sphere, the modulus was 0.36.

Hemispherical Cup. For a hemispherical cup (such as is used on Robinson's anemometer): when the convexity was to the wind the modulus was 0.36; when the concavity was to the wind the modulus was 1.15.

Retaining Surfaces. When a surface parallel to the direction of the wind was brought nearly into contact with a cylinder or sphere, the pressure on the latter bodies was increased by about 20 per cent., owing to the checking of the lateral escape of air.

Sheltering Surfaces. When a 9-in. disk was used as a sheltering surface and a 6-in. disk was placed 2 in. in front of it, the latter received only two-thirds the pressure it endured if the larger disk was removed. This reduction in pressure was perceptible, though to a less extent, at all distances up to 9 in.

Temperature Effects on Train Resistance. Train resistance increases with an increase of journal lubricant viscosity; thus when the viscosity of the journal lubricant is increased by the lowering of atmospheric temperature an increased train resistance results. Tests have indicated that at the atmospheric temperatures of ordinary railway operation, train resistance decreases as the journal lubricant becomes less viscous with rising journal temperature,

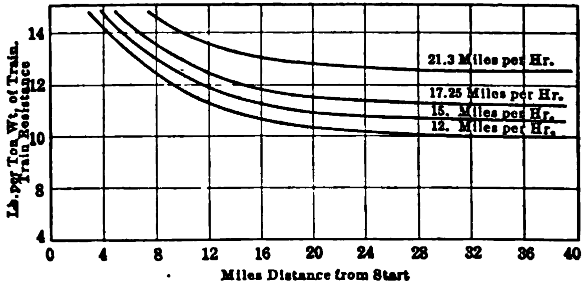


FIG. 37.—Decrease of freight train resistance as train progresses (Univ. of Ill. tests).

other conditions being constant. When a constant journal temperature is reached on a moving train, the train resistance is at a minimum for the then prevailing track conditions, speed of train and temperature of the atmosphere. Figs. 37 and 38 by Professor Edward C. Schmidt and F. W. Marquis, taken from bulletin No. 59 of the University of Illinois Experiment Station, were plotted from data secured from thirty-two tests. The tests were made in 1910 with trains on the Illinois Central Railroad as they came in regular service. Fig. 37 indicates that the mean resistance at speeds of from 12 to 35 miles per hour, and atmospheric temperatures from 30 to 42 deg. F., became a minimum when the train had been in motion for about 35 miles. It was found that in warm weather the minimum train resistance for a similar train was reached when the train had been in motion from 8 to 10 miles. Fig. 38 gives a comparison of minimum train resistance values for the two atmospheric temperatures and shows that the minimum train resistance in cold weather is approximately 25 per cent. greater than in warm weather.

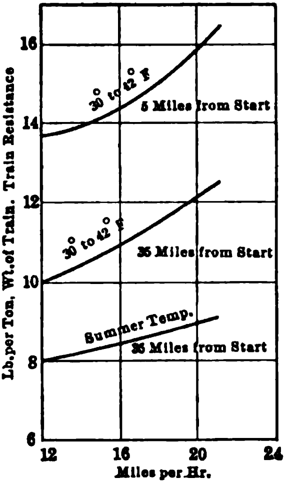


FIG. 38.—Effect of temperature on train resistance (Univ. of Ill. tests).

Effect of Temperature on Power Station Load. Fig. 39, from Elec. Ry. Journal, 1911, shows the effect of temperature on power station load. It should be noted that the power used for heating is included in these curves. The statement accompanying the curves is as follows:

In summer the peak loads are between 70 per cent. and 75 per cent. of the winter loads. This is accounted for largely by the use of light open cars on many lines and the fact that there is no demand for heat, and also by the fact that the car resistance in warm weather is less than in cold weather. The last two factors produce a striking relation between the load of the system and the atmospheric temperature, which is well illustrated by the diagram. An increase of approximately 400 kw. in the total load on the system results from a decrease of 1 deg. in the atmospheric temperature. The night load between 1 a.m. and 5.30 a.m. averages about 3000 kw. in the summer months and 5000 kw. in the winter months.

Starting Resistance. (Recommended conclusion, Com. Economics of Ry. Location, Am. Ry. Eng. & Maint. of Way Assn., 1910.) The starting resistance of a train on tangent level track varies from 10 to 40 lb. per ton weight of train, depending on loading, temperature, character and condition of the track and train.

Curve Resistance. Curve resistance may be defined as the resultant force, due to track curvature, which opposes the motion of a train at a constant speed on a curved track. It is equal to the tractive effort at the driving wheel treads necessary to keep a train moving at a constant speed on a circular curve of level track in still air, in excess of that necessary to keep the train moving at a constant speed on tangent level track of the same character in still air. Curve resistance is commonly expressed in pounds per ton weight of train per degree of track curvature. For convenience it is also often expressed in terms of grade, that is, in terms of that per cent. grade whose grade resistance would be equal to the curve resistance under consideration. (See opposite page.) Many values of curve resistance have been determined by experiment, but the variables concerned are such that no rational method for the general calculation of it has yet been determined. In ordinary cases, the value of curve resistance is small compared with train resistance and grade resistance; also, but a small portion of the total track of any usual railway is curved; therefore, in ordinary cases an accurate determination of curve resistance is of minor importance. Curve resistance is due to the increased slippage between wheel (tread and flange) and rail and increased friction in the moving parts of the train on the curve. Its value depends primarily on the coefficient of friction between wheel and rail, length of truck wheel base, gage, flexibility and condition of the track and the condition of the rail surface. The value of curve resistance on moderate curves is nearly proportional to the degree of curvature. On curves of short radius it is less per degree of curvature than on curves of greater radius. On curves of very short radius, such as are usually found in city streets, conditions are such that no definite statement of the value of train resistance for those curves can be given.

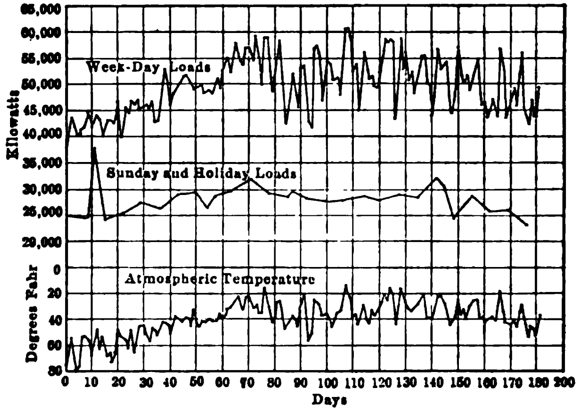


FIG. 39.—Effect of temperature on power station load (Boston Elev. Ry.)

Grade Compensation. In order that the combined up grade and curve resistance on a curve may be equal to the grade resistance on tangent track having a grade equal to that originally on the curve, the grade is often reduced by the amount whose grade resistance would be equal to the curve resistance. This reduction of grade on curves is called "grade compensation."

Determination of Curve Resistance (and Grade Compensation). The Committee on Economics of Railway Location (1910) of the Am. Ry. Eng. and Maint. of Way Assn. reported tests at North Mountain Cut-off and Mt. Airy Grade on the Baltimore and Ohio R. R. to determine the effect of curve compensation. The trains used in these tests were made up of locomotive, dynamometer car, thirty and thirty-six steel hopper cars (empty and loaded) and caboose. On portions of the grade compensated at the rate of 0.03 per cent. per degree of curvature the combined up grade and curve resistance was greater than on tangent track, while on portions compensated at the rate of 0.04 per cent. per degree of track curvature the combined up grade and curve resistance was less than on tangent rack. Assuming that the mean of these rates, 0.035 per cent. per degree of track curvature, was the correct rate of compensation the curve resistance was 0.7 lb. per ton weight of train per degree of track curvature. In reply to a circular addressed by the committee to several operating companies to determine the best amount of compensation, values ranging from 0.02 per cent. to 0.08 per cent. per degree of track curvature were received, but the consensus of opinion was that 0.035 per cent. gave the best results. That indicates the following formula as giving a probable value of curve resistance:

$$c = 0.7D$$

Significance of symbols:

c = curve resistance, pounds per ton weight of train
D = track curvature, degrees
$= \frac{5730}{R}$
R = radius of track curvature, feet
$= \frac{5730}{D}$
a = wheel base of a truck, feet.

Other Formulas for Curve Resistance.

Significance of symbols as above.

RAYMOND FORMULA: $c = 0.4 + (0.205 + 0.035a)\,D$
$= 0.780D$ for 5 ft. truck wheel base
$= 0.815D$ for 6 ft. truck wheel base
$= 0.860D$ for 7 ft. truck wheel base
$= 0.885D$ for 8 ft. truck wheel base
$= 0.920D$ for 9 ft. truck wheel base
$= 1.025D$ for 12 ft. truck wheel base.

BLONDEL-DUBOIS FORMULA: $c = \frac{3765}{R} = 0.66D.$

DUPUI FORMULA: $c = \frac{2427}{R - 32.8}.$

Grade Resistance. The component of force along a line parallel to the center line of the track, due to the action of gravity on a train, is called grade resistance. Grade resistance is commonly expressed in pounds per ton weight of train. If the direction of grade resistance is opposite to the direction of motion of the train (that is, if the train is on an up grade) the tractive effort will be decreased by the value of the grade resistance. If the direction of grade resistance is the same as the direction of motion of the train (that is, if the train is on a down grade) the tractive effort will be increased by the value of the grade resistance.

Approximate Value of Grade Resistance. The following formula will give results slightly in excess of the true values, but close enough for all ordinary traction work. The error is greater with heavier grades, but reaches only 0.5 per cent. for a 10 per cent. grade.

$$G = 20Wn$$

in which G = grade resistance, pounds per ton weight of train
W = weight of train, tons
n = number of per cent. of track grade
= one hundred times the rise of the track in any distance, divided by that distance, that is, one hundred times the tangent of elevation of the track.

This formula may be stated in the form of a rule:

Grade resistance is equal to 20 lb. per ton weight of train per per cent. of grade.

Actual Value of Grade Resistance. The precise value of grade resistance may be expressed by the formula

$$G = \frac{2000\,Wn}{\sqrt{10{,}000 + n^2}}$$

in which the symbols are the same as in the preceding paragraph.

It is interesting to note that the above rule for obtaining the *approximate* value of grade resistance yields the *precise* value of grade resistance if the per cent. grade used in applying the rule is the approximate per cent. grade obtained according to "Approximate Value of Grade," p. 142.

Acceleration

Linear Acceleration.

$$I = \frac{2000}{32.2} \times 1.467 \times A$$
$$= 91.1A = \frac{A}{0.01098}$$

in which I = force necessary for the linear acceleration of the mass of one ton weight at the rate A, pounds
91.1 = force necessary to give the mass of one ton weight an acceleration of 1 mile per hour per second, pounds
A = rate of linear acceleration, miles per hour per second.

Ratio of Force Necessary for Linear Acceleration to Force Necessary for Total Acceleration. As the total effective inertia of rotating parts is greater than their inertia when moved as a mass in a straight line, allowance must be made for this fact in the consideration of train acceleration. This is particularly true in the case of electric motor cars, the geared armatures of which often rotate at considerably higher speed than the car wheels. The ratio of the "linear inertia" to the "total inertia," including that of rotating parts, may be expressed by K, in the expression:

$$\frac{I}{F} = K$$

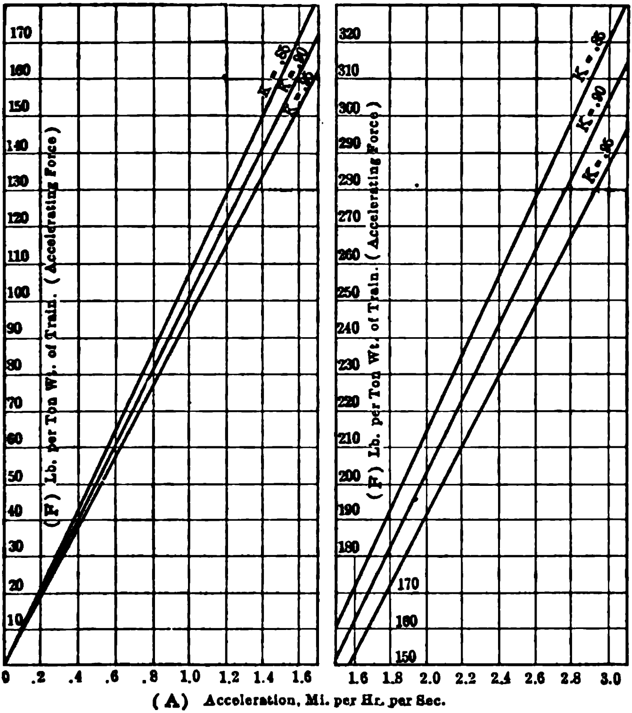


FIG. 40.—Force required for train acceleration.

where I = force necessary for linear acceleration, pounds per ton weight of train

F = total force necessary to accelerate the train, pounds per ton weight of train

K = ratio of linear inertia to total inertia of train.

Force Necessary to Accelerate Train.

$$F = \frac{91.1A}{K} = \frac{A}{0.01098K}$$

the symbols having the same significance as in the two preceding paragraphs. A graphical solution of this equation is given by Fig. 40. For a rough approximation, $F = 100$ lb. per ton weight of train per mile per hour per second or $F = 100A$. This is due to the fact that the value of K approximates an average of 0.911.

Ratio of Linear Inertia to Total Inertia.

$$K = \frac{I}{F} = \frac{W}{W + n_w W_w \left(\frac{r_w}{R_w}\right)^2 + n_a W_a \left(\frac{r_a R_a e}{R_a R_w}\right)^2}$$

in which W = weight of car complete, car or locomotive
W_w = weight of car wheel
W_a = weight of motor armature
n_w = number of car wheels
n_a = number of motor armatures
R_w = radius of car wheel at tread
R_a = radius of motor armature
r_w = radius of gyration, car wheel
r_a = radius of gyration, motor armature
e = gear ratio
F = total effective inertia ($= I + i$)
I = linear inertia
i = rotational inertia
$\left(\frac{r_w}{R_w}\right)^2$ = approximately 0.6 for the average car wheel
and $\left(\frac{r_a}{R_a}\right)^2$ = approximately 0.5 for the average railway armature.

Substituting these values the formula becomes:

$$K = \frac{W}{W + 0.6 n_w W_w + 0.5 n_a W_a \left(\frac{R_a e}{R_w}\right)^2}.$$

The value of K for a train made up of units (motor cars, motor cars and trail cars, or locomotives and trail cars) is equal to the sum of the values obtained by multiplying the value of K for each individual motor car, locomotive, or trail car by the ratio of the weight of that particular car or locomotive to the weight of the whole train.

Ratio of Linear Inertia to Total Inertia in Practice.

For electric locomotive and heavy freight train, $K = 0.95$
For electric locomotive and high-speed passenger train, $K = 0.935$
For high-speed electric motor car, $K = 0.935$ to 0.91
For low-speed electric motor car, $K = 0.91$ to 0.85.

Economical Rates of Acceleration. Acceleration is limited by the capacity of the equipment, the coefficient of adhesion and the comfort of the passengers. Ignoring the last, the most economical rate of acceleration for a given section will depend upon

(1) the frequency of service, (2) train weight and (3) the capacity of the equipment. If, with the same schedule speed, the acceleration be increased, there will result a slight saving in energy due to the lessened train resistance at the lower maximum speed attained. There will also be a very important saving in energy due to (1) the possibility of a longer coast, allowing braking to begin at a lower speed (the losses in braking being proportional to the square of the speed at which braking begins), and (2) with direct-current equipments a saving in rheostatic losses, which are inversely proportional to the rate of acceleration.

In very frequent service, such as is found in the operation of a large city system, the rate of acceleration is practically only limited by the capacity of car equipments and the comfort of the passengers, because the capacity of the generating and distributing system is not limited by the peak loads of individual car units.

Where the service is infrequent, as in the case of interurban sections, the acceleration is often limited by the low tension distribution and substation capacity. This limitation may, however, be greatly reduced with the retention of a fair average rate of acceleration and its attending benefits by using a high rate of acceleration during series acceleration and a considerably less rate during multiple acceleration. The effects of such a procedure are shown by the typical speed-time curves and corresponding current curves in Fig. 41. In case *A*, constant current per car is used throughout both series and parallel connections of the motors; this is done by allowing the controller to rest in full series position until the value of current is one-half of what it was during the series acceleration. In case *B*, with a constant rate of straight line acceleration the value of the current per car when the motors are in parallel is double that when they are in series; in other words, the current per motor is kept constant. In case *A*, for this particular run the rates of straight line acceleration are approximately 1.5 and 0.6 mile per hour

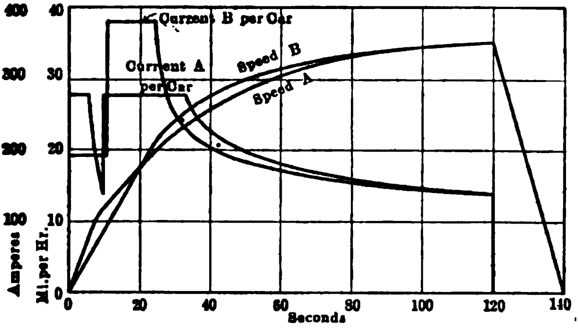


FIG. 41.—Reduction of maximum current by use of lower rate of acceleration in multiple than in series.

per second. In case *B*, the straight line acceleration is approximately 0.9 mile per hour per second throughout. Practically the same energy is used in both cases but the maximum value of current in case *A* is only about 73 per cent. of that in case *B*. Another method of using two rates of acceleration in the series and parallel positions of the controller is an intermediate one, where the controller is so operated that the current per car with motors in parallel is greater than when in series, but less than double, as in case *B*. The maximum current is then somewhere between the values in cases *A* and *B*. An article by F. E. Wynne in the Electric Journal, 1908, states that for hilly roads this third method is found more satisfactory than the method of case *A*. He also states that on runs of ¾ mile or less, the acceleration with constant current per motor (case *B*) is less economical of energy than either of the other methods which are about on a par with each other, but on longer runs the energy consumption is practically the same with all three methods.

Comfortable Rates of Acceleration. It should be remembered that the effect of acceleration on the comfort of passengers is not so much a measure of the rate of acceleration as of the rate of change of accelerating rate. Referring to Fig. 42, the rates of acceleration and of braking as shown by the full lines may be uncomfortable to passengers, due to the abrupt start, application of brakes, and stop. However, if the starting resistance on the first controller position be so proportioned as to give the start shown by the dotted line at *A*, and the brakes be gradually applied and released so as to introduce the curves shown by the dotted lines at *B* and *C*, very high rates of acceleration and braking may be employed without causing discomfort to passengers. The addition of these curves may lengthen the time of run by a few seconds, but this must be done if high rates of acceleration be employed.

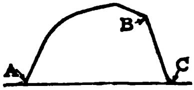


Fig. 42.

Effect on Draft Gear and Other Car Equipment. The above remarks, relative to comfort of passengers, apply equally to shocks to draft gear in train operation and to other parts of the car equipment. To reduce these shocks it is necessary to keep down the rate of change of accelerating rate.

Usual Rates of Acceleration in Practice.

Steam locomotives, freight service	0.1 to 0.2 mi. per hr. per sec.
Steam locomotives, passenger service	0.2 to 0.5 mi. per hr. per sec.
Electric locomotives, passenger service	0.3 to 0.6 mi. per hr. per sec.
Electric motor cars, interurban service	0.8 to 1.3 mi. per hr. per sec.
Electric motor cars, city service	1.3 to 1.8 mi. per hr. per sec.
Electric motor cars, rapid transit service	1.5 to 2.2 mi. per hr. per sec.
Highest practicable rates	2.5 to 3.0 mi. per hr. per sec.

The average rate of acceleration on the Second Ave. line, N. Y., which is representative of the entire Manhattan Elevated system, is 1.33 miles per hour per second. The maximum possible rate of acceleration is limited by the available tractive effort which is dependent not only upon the motor equipment and weight of train but also upon the coefficient of adhesion between wheel and rail.

AVERAGE ACCELERATION DURING FIRST TEN SECONDS, VARIOUS WEIGHTS OF TRAIN, ELECTRIC AND STEAM

Number of trailers	0	1	2	3	4	5	6
Total weight of trailers, tons	.....	23.00	47.00	77.00	104.00	130.00	157.00
Electric:							
Two motor cars, total weight 71.5 tons; total weight of train, tons	71.50	94.50	118.50	148.50	175.50	201.50	228.50
Average rate of acceleration of train first 10 seconds, miles per hour per second	2.75	2.25	2.07	1.73	1.44	1.26	1.12
Steam:							
Locomotive, weight 107 tons; total weight of train, tons	.....	130.00	154.00	184.00	211.00	237.00	264.00
Average rate of acceleration of train during first 10 seconds, miles per hour per second.	.....	1.40	1.30	1.25	1.20	1.00	0.97

The above data are from results of experimental tests at Schenectady, N. Y. (Arnold and Potter, A.I.E.E., 1902). The acceleration was practically constant during the first 10 seconds of each run from which these figures were taken. The principal purpose of the test was to afford a comparison between steam and electric traction on short haul suburban passenger service. The steam locomotive was designed especially for a high rate of acceleration. All axles of both motor cars were equipped with motors. The run curve for the test of the two motor cars without trailers indicates a maximum rate of acceleration of about 3.3 miles per hour per second during the sixth, seventh and eighth seconds of the run.

Graphical Representation of Acceleration. The slope of any increment of a speed time curve plotted between time in seconds as abscissas and speed in miles per hour as ordinates is numerically equal to the rate of acceleration in miles per hour per second.

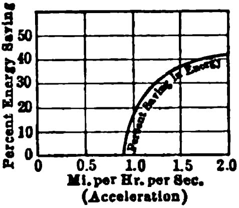


FIG. 43.

Relation Between Acceleration and Maximum Speed Attained During Run. As noted in the section on Run Curves, the dotted line in Fig. 58 (p. 192) is the locus of the maximum speeds attained during a run of 1 mile, assuming coasting, braking retardation and train resistance constant. This figure, as well as Fig. 60 (p. 193), illustrates the fact that for a given run the maximum speed is reduced by increasing the rate of acceleration.

Personal Factor and Rate of Acceleration. In an A.I.E.E. paper, 1910, Mr. H. St. Clair Putnam states that in tests on the entire Manhattan (N. Y.) system, the rate of acceleration of the different motormen was found to vary from 0.9 to 1.47 miles per hour per second.

Influence of Rate of Acceleration on Energy Consumption. Fig. 43, from data given by the same paper, shows the importance of a high rate of acceleration in a typical run. This is also shown in a more general way by Fig. 69 (p. 218).

Wimperis Accelerometer. The essential parts of the Wimperis accelerometer are shown by Fig. 44. The circular metallic disk pivoted at the center of its circumference is of uniform thickness and has a hole punched through it near its edge. The disk pivot also carries a spur gear which meshes with a like gear fastened to a second pivot carrying the index. A coil spring on the disk spindle brings the parts back to their zero positions when acceleration or retardation has ceased. The two pivoted systems are so arranged that the moments of their masses about their respective axes of rotation are equal so that the instrument when leveled up will indicate acceleration or retardation in the direction of motion independently of effects of track curvature or super-elevation of the outer rail. Oscillations are damped by the magnetic field perpendicular to the disk.

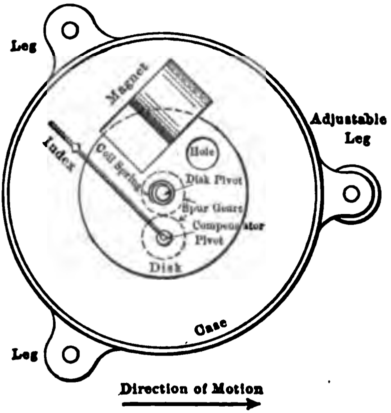


FIG. 44.—Wimperis accelerometer.

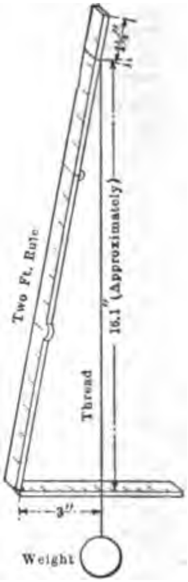


FIG. 45.—Improvised accelerometer.

Improvised Accelerometer. A readily improvised accelerometer is shown in Fig. 45. It consists of an ordinary 2-ft. four-fold pocket rule, a piece of thread and a weight. Eighteen inches of the rule is opened out straight and the thread is tied to this part at a point 1⅝ in. from the end; the weight is tied to the other end of the thread, and the remaining 6 in. of the rule is opened and leveled (extending in the direction of motion) till the plumb line cuts the 3-in. point of the base thus formed. About 16.1 in. of thread then hangs between the point of support and the base; consequently, each increment of 1 ft. per second per second acceleration or retardation will be indicated by a corresponding deflection increment of approximately ½ in. at the point at which the thread and the base line intersect. If the thread be attached at a point 6⅝ in. from the upper end, and the upper part of the rule bent further over until the plumb thread again cuts the 3-in. point, the deflection of each ½ in. due to acceleration or retardation will indicate 1 mile per hour per second.

Run Curves

The term "Run Curves" is a general one and embraces any curve or curves which show graphically the performance of a train by the values of speed, current, voltage, power, distance, or time plotted as ordinates, usually against time values as abscissas, although in some special cases distance values are used as abscissas.

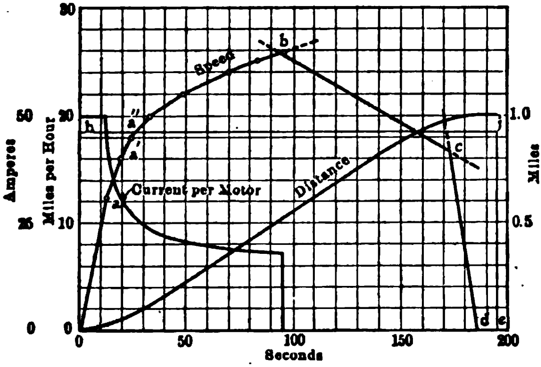


FIG. 46.—Typical run curves.

Run curves may take into consideration all the physical characteristics of the track over which the run is made, and may be plotted between any limits of time or distance. Especially for preliminary work, however, a "typical run" is usually chosen, representing average conditions of track grade and time of run from start to stop.

Determination of Typical Run. In selecting a typical run it is convenient to divide the line into general sections, for instance, city, suburban and interurban, and then use the approximate average length of run in a section for the length of the typical run for that section. If there are steep grades on the line there should also be a division into grade sections and a typical run selected for each of these. If the grades of a given section do not require braking, the "average grade" should be taken as the grade of the typical run for that section.

Speed time curve for a given train starting from rest or a known speed and running a given distance to a stop or other known speed at a given schedule speed. It is convenient to divide the speed-time curve up into the following principal parts which are given in the order in which they are usually constructed:

(1) Acceleration with motor current controlled, called for convenience, Straight Line Acceleration. (*oa*, Fig. 46.)

(2) Acceleration beyond Straight Line Acceleration, or "acceleration on the motor curve." (*ab*, Fig. 46.)

(3) Stand-still during stop allowed for in the schedule speed. (*de*, Fig. 46.)

(4) Braking. (*cd*, Fig. 46.)

(5) Coasting. (*bc*, Fig. 46.)

Scales. The speed-time curve shows the speed of the train at any instant during the run and is conveniently plotted between time in seconds as abscissas and miles per hour as ordinates.

(1) *Acceleration with Motor Current Controlled (Straight Line Acceleration) oa.*

$$\textit{Slope of } oa = A = \frac{\text{miles per hour}}{\text{seconds}}, \text{ drawn to scale.}$$

in which A = assumed acceleration, miles per hour per second, or the acceleration produced by the assumed maximum current per motor, found as below under (2).

Speed at a. The approximate speed of the train at *a*, Fig. 46, is determined from the motor characteristic curve, and is either the speed corresponding to (*a*) the assumed value of maximum current per motor in the full parallel position, or to (*b*) the tractive effort T determined in accordance with the following:

$$T = \frac{W}{n}\left(\frac{A}{0.01098K} + f + C \pm G\right)$$

in which T = tractive effort at driving wheel tread for one motor, pounds

W = weight of train, tons

n = number of complete motors having similar characteristics

A = rate of straight line acceleration, miles per hour per second

K = ratio of linear inertia to total inertia of train. (See page 172)

f = average train resistance of the train between the initial speed and an assumed probable approximate speed at *a* (Fig. 46), pound per ton weight of train

C = curve resistance, pounds per ton weight of train

G = grade resistance, pounds per ton weight of train. (Use (+) before this value for up grade and (−) for down grade.)

(2) *Acceleration Beyond Straight Line Acceleration* (*ab*). The curve *ab* is approximated by a succession of straight lines (aa', $a'\,a''$, etc., Fig. 46).

(Slope to scale of each of these lines) =

$$A = 0.01098K(P - f - C \mp G)$$

in which, for any part such as aa',

$$P = \frac{Tn}{W} = \text{tractive effort, pounds per ton weight of train.}$$

P, T, and f are taken as the mean of those values between the speeds a and a'. For this and other parts of the speed-time curve beyond the straight line acceleration portion, T is obtained from the motor tractive-effort characteristic curve. The sign of G is $(-)$ for up grade and $(+)$ for down grade. The point b will be determined by the final location of the coasting line bc.

Speed Increment. The speed at a is that of the last point previously determined on the curve, and the speed at a' is some greater assumed speed. The amount of the speed increment between a and a' will depend on the allowable error in approximation. For the same allowable error, this increment may be greater in the steeper than in the flatter portions of the curve.

(3) *Stop Period, de.* The time of run, in seconds, is

$$oe = \frac{\text{miles from start to stop} \times 3600}{\text{miles per hour schedule speed}}$$

and $od = oe - (\text{stop period in seconds})$

(4) *Braking Line, cd.* The slope to scale of the braking line cd is equal to the assumed rate of braking retardation. The point c is determined by the final location of the coasting line bc.

(5) *Coasting Line, bc.* The slope to scale of the coasting line bc is

$$A = 0.01098K(-f - C \mp G)$$

in which f = approximate average train resistance between the probable approximate assumed speeds at b and c, pounds per ton weight of train.

K, C and G are the same as before.

The line bc is placed so that area $(oabcd)$ = area of rectangle $(ohje)$

in which oh = schedule speed

and oe = time of run, including stop.

(See pp. 181 and 183 for more definite location of coasting line.)

Distance-time Curve. The distance traveled by a train during any definite period of time is proportional to the area bounded by the speed-time curve for the train during that period of time, the ordinates through the extremities of that period, and the axis of time. This distance is shown by the distance-time curve (Fig. 46) which may be plotted between elapsed time in seconds and feet or miles, on the same axis of time as that used for the speed-time curve.

Determination of Distance from Speed-time Curve. A method of obtaining the distance traveled during any elapsed time is as follows: The portion of the speed-time curve for this period of elapsed time is divided into increments of length depending upon the degree of accuracy to which the speed-time curve is drawn and the degree of accuracy desired. The distance increment corresponding to each of these speed-time increments is calculated as below, and all the distance increments for any elapsed time are then added together.

$$ds = \frac{V_m(t_2 - t_1)}{3600}$$

in which ds = distance increment, corresponding to any increment of the speed-time curve, miles

V_m = mean velocity of train during that increment, miles per hour

$(t_2 - t_1)$ = time elapsed while that increment accrued, seconds.

The same result may be attained by the use of a planimeter, integrating the area above described, when

$$ds = \frac{ats}{3600}$$

where ds = distance increment, as above, miles

t = number of seconds per unit of ordinate

s = number of miles per hour per unit of abscissa

a = area, in square units.

units may be inches, centimeters, etc., as desired, but t, s, and a must all refer to the same unit.

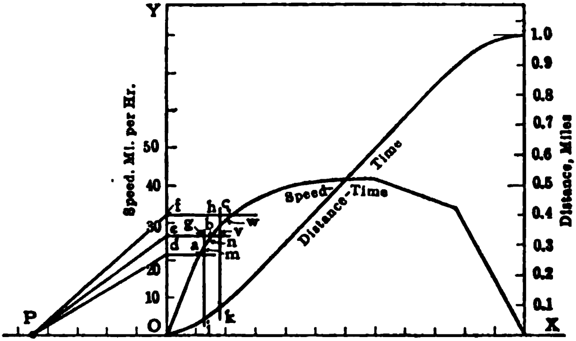


FIG. 47.—Graphical construction of distance time curve.

Graphical Construction of Distance-time Curve. The following graphical method for the construction of the distance-time curve is adapted from a description by Mr. J. G. Pertsch in the Sibley Journal of Engineering in 1910. The process will be described for one short section of the distance-time curve, *jk* (Fig. 47), assuming that the speed-time curve is complete and that the portion *Oj* of the distance-time curve has been drawn. Through various points *a*, *b*, *c*, etc., on the speed-time curve (including especially the points of maximum and minimum speed) draw lines parallel to *OX* and intercepting *OY* at *d*, *e*, *f*, etc. Draw lines *gj*, *hk*, etc., perpendicular to *OX*, and at such positions that the small triangles formed on each side of such lines by the speed-time curve and the horizontal lines previously drawn, will be equal in area. (Note that triangle m should equal triangle n, and $v = w$, but that triangles n and v are not necessarily equal.) Locate point P, to the left of O, and on OX prolonged, as follows:

Let d = any distance, miles

s = the speed, miles per hour, whose ordinate value on the speed scale is the same as that of d on the distance scale

$$t = \frac{d \times 3600}{s}, \text{ in seconds}$$

OP = value of t, on time scale.

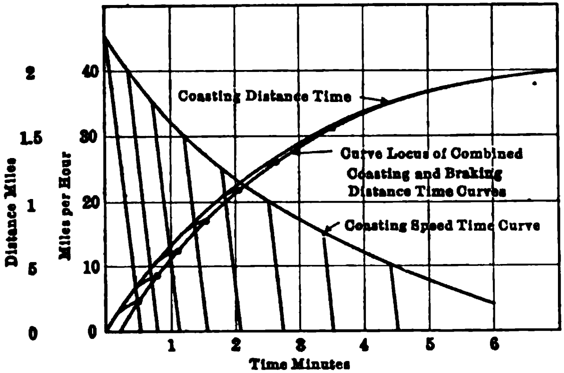


FIG. 48.—Construction of templet for coasting curve.

Then draw the various lines Pd, Pe, Pf, etc. The average slope of the distance-time curve between the perpendiculars gj and hk will then be the same as Pe, and the portion jk may be drawn as a straight line parallel to Pe and joining the portion Oj previously drawn. The final distance-time curve will be a smooth curve drawn tangent to the short straight line sections such as jk.

Templet Method of Locating Coasting Portion of Speed-time Curves. Mr. F. S. Valentine, in Elec. Jour. (1908), describes a method of accurately locating the coasting curve which is of considerable value where a large number of speed-time curves are to be plotted for the same value of train resistance, track grade and curve resistance and braking rate, with varying times and distances between stations. This method employs a celluloid templet, constructed as follows: The coasting speed-time curve corresponding to the total train resistance (including track grade and curve resistance, if any) for the cases in hand is plotted from a speed somewhat greater than the maximum possible speed under the given conditions, as shown in Fig. 48. Speed-time braking curves are drawn in at the given braking rate, as shown, at frequent intervals. The distance-time curve for coasting is then drawn, with distance-time curves for the various braking speed-time curves. The terminal points of these combined coasting and braking distance-time curves are shown by the black dots in Fig. 48, and through these terminal points a smooth curve is plotted as shown. The latter is a locus curve of any or all coasting and braking distance-time curves. The coasting speed-time curve is inscribed on thin celluloid, and it is trimmed so that its edges will coincide with the *X* and *Y* axes of the curve. This templet is then inverted, keeping the *Y* axis of the templet on the *Y* axis of the curve, and in the inverted position (1) the coasting distance-time curve and (2) the locus of the combined coasting and braking distance-time curves are traced on the templet. The complete templet, which is finally trimmed along the "locus" curve, appears as in Fig. 49. The use of the templet is as follows, referring to Fig. 50. Assuming that it is desired to complete the run shown in 3.5 minutes between stations 2 miles apart, a needle point is inserted at *D*, corresponding to these two requirements. Apply the templet so that the curved edge will always be in contact with the needle *D*, keep the *Y* axis of the templet always parallel with the *Y* axis of the curve, and adjust

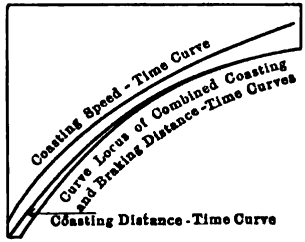

Coasting Speed - Time Curve
Curve Locus of Combined Coasting and Braking Distance-Time Curves
Coasting Distance - Time Curve

Fig. 49.—Sample templet for coasting curve.

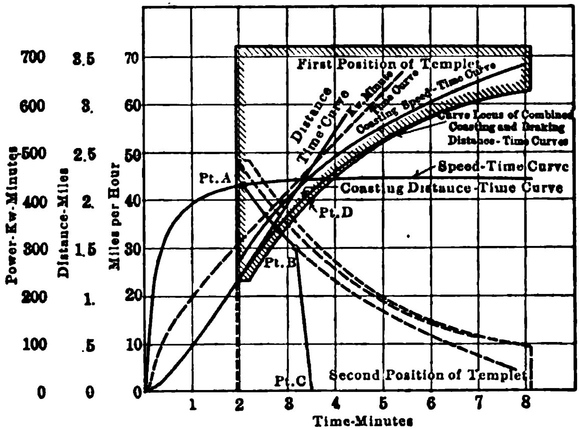


Fig. 50.—Use of templet for coasting curve.

until the coasting distance-time curve on the templet is tangent to the acceleration distance-time curve. (See "First Position of Templet," Fig. 50.) This point of tangency is at the time when power is cut off and the train begins to coast. To locate this time more definitely, insert a needle point at some point along the *Y* axis of the templet and invert the templet so that its *X* axis coincides with the *X* axis of the curve and its *Y* axis touches the needle point. (See "Second Position of Templet" dotted lines, Fig. 50.) The point *A* at which the coasting speed-time curve on the templet crosses the acceleration speed-time curve is the point at which power is cut off and coasting begins. In the construction of speed-time curves where the item of energy is concerned, it is most important that the time at which power is cut off be accurately determined, and in such cases it is recommended that either the above method or the one described below be employed.

Location of Coasting Line when Brakes are to be Applied at a Given Speed. Construct the acceleration portion of the speed-time curve and its corresponding distance-time curve, and carry both to a time somewhat beyond that at which it is assumed coasting will begin. These curves should be plotted on tracing paper or cloth, and will be similar to those shown by the solid lines in Fig. 51. (For figure 51 grades, see page 190.) Next, on a second sheet of paper, and to the same scales, begin at the end of the run and plot the braking and coasting speed-time curves up to a speed somewhat in excess of that where it is assumed coasting will begin. The distance-time curve for braking and coasting should also be plotted on the second sheet, beginning at the proper distance ordinate for the end of the run (1.7 miles in Fig. 51). The curves on the second sheet will appear as shown by the dotted lines in Fig. 51. Then place the second sheet under the first, and keeping the base lines coinciding, slide one under the other until the two speed-time curves cut one another on the same vertical ordinate as that of the point of tangency of the two distance-time curves (*cc'*, Fig. 51). The speed-time and distance-time curve to the right of this ordinate

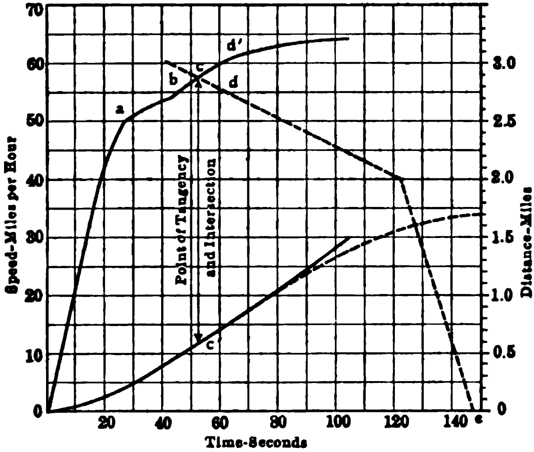


FIG. 51.—Method of joining retardation and acceleration curves.

on the second sheet (dotted lines, Fig. 51) may now be traced on the first sheet and the curves are complete for the run, and show not only the time at which power should be cut off in order to coast down to the given speed for applying brakes, but also the total time required for the run under the assumed conditions.

Speed-time Curve for Train over Given Section of Track with Varying Grades and Alinement. When it is required to plot a speed-time curve for a train over a given track, taking into consideration the effect of definite track grades and curvature, it is convenient to divide the total distance into consecutively numbered sections, each of which is uniform throughout its length with respect to track grades and curvature. A tabulation should then be made, with the following headings (compass points are relative only).

I. Consecutive number of section (beginning at west end).
II. Length of section (feet or miles).
III. Percentage of track grade ("+" for down, "−" for up grade in east-bound direction).
IV. Degree of track curvature.
V. Track curvature expressed as "equivalent grade" (as explained below: always with "−" sign).
VI. Net equivalent grade, east-bound.
VII. Net equivalent grade, west-bound.

As the values of resistance due to track curves and that due to grades are functions only of the degree of curvature and the percentage of grade, respectively, the degree of track curvature (Col. IV) may be expressed in terms of "equivalent grade" (Col. V) as follows:

$$g' = \frac{nc}{20}$$

in which n = number of degrees of track curvature
c = track curve resistance, pounds per ton per degree of curvature. (See p. 169.)
g' = "equivalent grade," per cent., which would cause a resistance equal to the curve n.

If the values in Cols. III and V have been given "+" or "−" signs as above, their algebraic sums will give the proper values for Col. VI; reversing the signs in Col. III and adding the values in Col. V will give the proper values for Col. VII.

Using Cols. VI and VII values (multiplied by 20) for G', the formula for acceleration becomes

$$A = 0.01098K(P - f \mp G')$$

with but three variables instead of four, as before.

The speed-time curve may then be plotted as before described, but the distance-time curve must be plotted at the same time. The distance-time curve, in connection with the distance values as shown in Col. II of the tabulation, will show the time ordinate at which the acceleration formula must change by the substitution of a new value for the equivalent grade, G'. It is advisable to use the method described on p. 183 to locate the coasting and braking curve. The completed curve will be similar to that shown in Fig. 51.

Chart of Acceleration Coefficients. Where a considerable number of speed-time curves are to be plotted for the same equipment, the "chart of acceleration coefficients" as proposed by Mr. C. O. Mailloux (A.I.E.E., 1902) becomes most convenient. This chart, a sample of which is shown by Fig. 52, is plotted with rates of acceleration as ordinates and miles per hour speed as abscissas. Curve

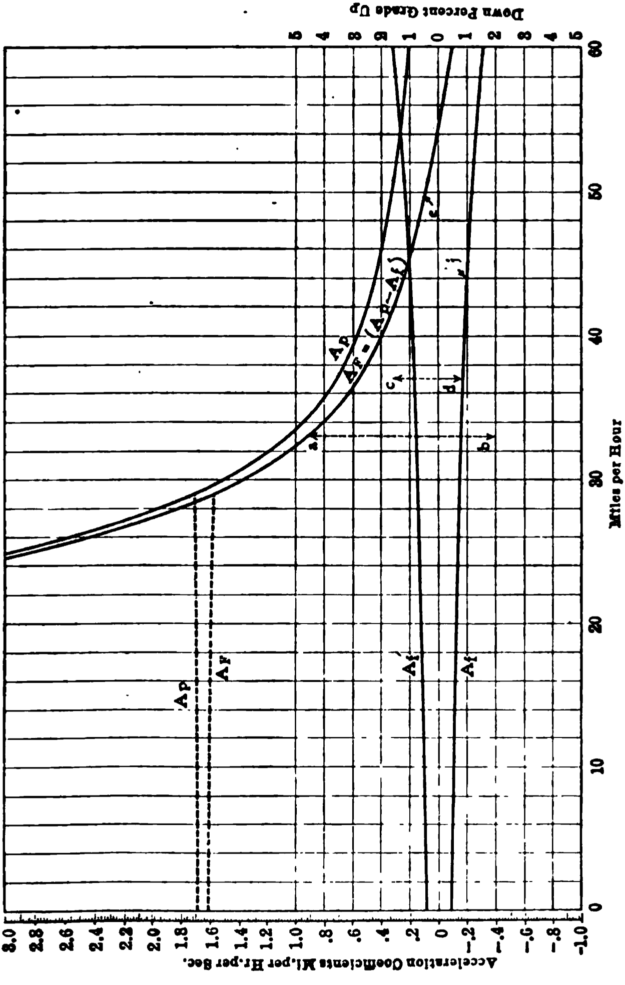


FIG. 52.—Typical chart of acceleration coefficients.

A_p is the solution of $A_p = 0.01098KP$ with $P = \frac{Tn}{W}$ for the particular equipment in hand, values of tractive effort being taken for various speeds from the motor characteristic curve. Curve A_p may be plotted between the limits of maximum possible motor current and maximum safe motor armature speed. The dotted line A_p corresponds to the current per motor (constant or not, as assumed) during the period in which it is under control, by rheostat or otherwise. Curve A_f is the solution of $A_f = 0.01098K(-f)$ with f the value of train resistance for the particular equipment at various speeds. Curve A_f' is the same as Curve A_f reproduced above the X axis. Curve A_F is the solution of $A_F = 0.01098K(P - f) = 0.01098KP - 0.01098Kf$, and therefore its ordinates are the algebraic sum of the ordinates of Curves A_p and A_f, or the ordinate distance (which may be measured with a pair of dividers) between curves A_p and A_f'. Lines are drawn above and below and parallel to the X axis, at ordinate distances therefrom equivalent to solutions of $A_G = 0.01098K(\pm G)$, and marked, as at the right of Fig. 52, with the per cent. grade to which they correspond.

If track curvature be expressed as "equivalent grade," as explained on p. 184, the chart may be used for any solution of the acceleration formula $A = 0.01098K(P - f - c \pm G)$ for the particular equipment in hand. For the rate of acceleration, with motor current applied, at any speed and on any (equivalent) grade, take the ordinate value (on that speed ordinate) between curve A_F and the line for that particular grade. For the rate of acceleration during coasting, take the ordinate value between A_f and the grade line. Ordinate values measured below A_F or A_f are positive, above are negative. The speed abscissa on which curve A_F cuts any grade line indicates the speed at which $A = O$, or the maximum uniform speed which will be maintained on that grade, with current on. Likewise, the speed abscissa at which A_f cuts any grade line indicates the maximum uniform speed at which coasting will be maintained on that grade. The following solutions have been indicated on Fig. 52.

Rate of acceleration, power on, at 33 miles per hour, on 2 per cent. down grade = 1.32 miles per hour per second (length of ordinate *ab*).

Rate of retardation, coasting, at 37 miles per hour on 1½ per cent. up grade = 0.46 miles per hour per second (length of ordinate *cd*).

Maximum constant speed, current on, on 0.5 per cent. up grade = 49.5 miles per hour (*e*).

Maximum coasting speed on 1 per cent. down grade = 44.0 miles per hour (*i*).

In the practical use of the chart, the ordinate value between curve A_F or A_f and a grade line is most conveniently measured by a pair of dividers, transferring the measurement to the A scale at the left of the chart. If some care be exercised in the original construction of the chart, and it be made to a sufficiently large scale, rates of acceleration may be very rapidly determined to an accuracy of 1/100 mile per hour per second.

Chart of Reciprocals. For use in connection with the above described chart of acceleration coefficients, Mr. Mailloux proposes a "chart of reciprocals," a sample of which is shown in Fig. 53. Rates of acceleration are plotted as ordinates (to the same scale as that used in the Chart of Acceleration Coefficients (Fig. 52)) against time values as abscissas. Various reciprocal curves are then drawn, the true reciprocal curve being marked "1 mile per hour," the half reciprocal curve "0.5 mile per hour," the twice reciprocal curve "2 miles per hour," etc., between the limits of speed increments desired. The chart is so drawn to take advantage of the relation: time increment $= \dfrac{\text{velocity increment}}{\text{acceleration}}$ and shows the time required to make a given increment of speed at a given rate of acceleration. In its practical use, the length of ordinate representng the rate of acceleration is taken off the chart of acceleration coefficients with a pair of dividers, one point of which is then moved along the X axis of the chart of reciprocals until the other point cuts the required speed increment curve; the abscissa on which this occurs indicates the time increment directly. Thus the coordinates of the terminating point of a speed-time curve increment are definitely located, obviating the possible errors likely to result from drawing this increment at a slope corresponding to a rate of acceleration. Obviously, the chart of reciprocals is a general one and one such chart may be used in connection with any number of charts of acceleration coefficients, provided only that all are drawn to the same scale of rates of acceleration.

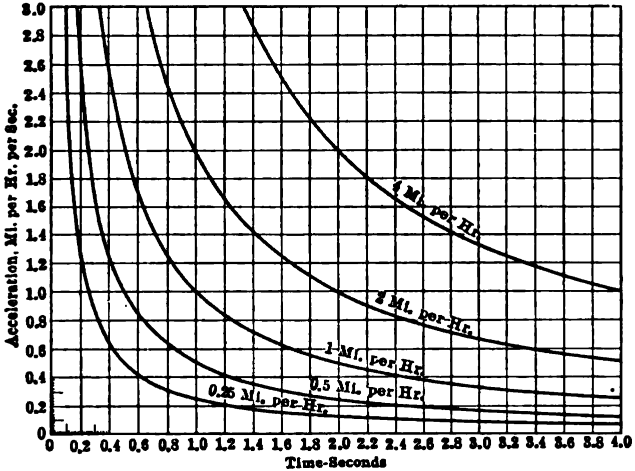


FIG. 53.—Typical chart of reciprocals.

Tracing Method of Construction of Speed-time Curves. Where speed-time curves are to be drawn for a considerable number of runs with the same equipment, especially with varying track grades and lengths of run, a most convenient method is one described by Mr. C. O. Mailloux (Trans. A.I.E.E., 1902). A given motor start-

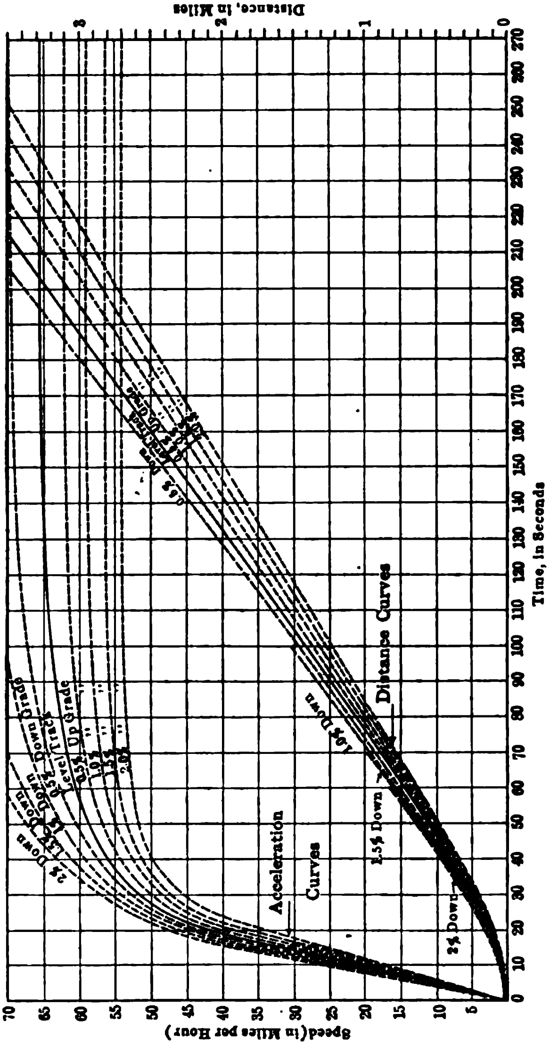


FIG. 54.—Typical speed and distance curves.

ing current having been assumed, a number of accelerating speed-time curves are drawn, for level track and various percentages of up and down grades; these are drawn to the same scales as have been

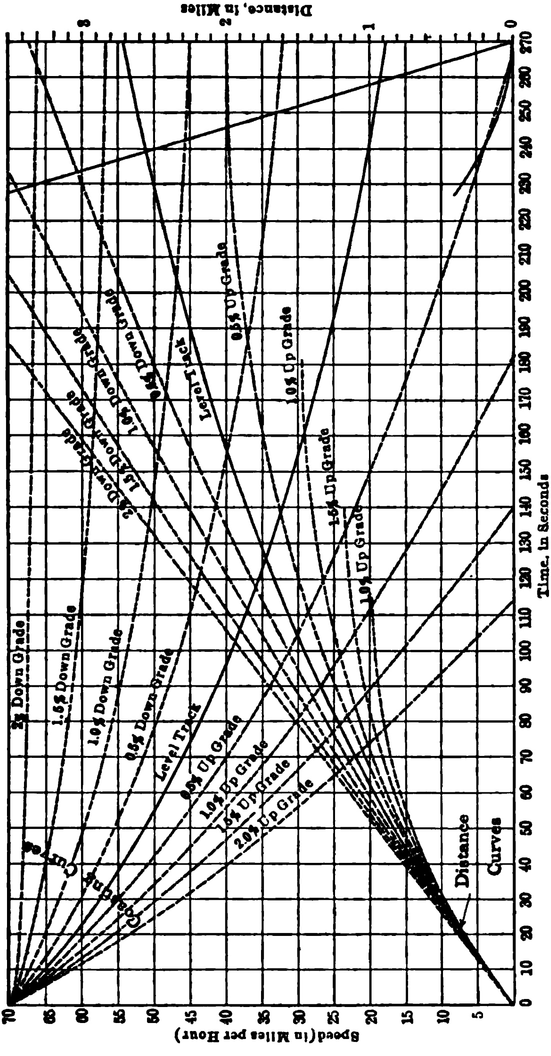


FIG. 55.—Typical coasting, braking and distance curves.

chosen for the final curves; corresponding distance-time curves are also drawn on the same axes (Fig. 54). On a second sheet, to the same scales, coasting speed-time curves and distance-time curves are drawn, for level track and various grades (Fig. 55). Some care should be exercised in constructing these two charts accurately. Curves on both charts should be drawn between the limits of the maximum grades to be encountered, and a sufficient number of both accelerating and coasting curves should be drawn so that the curves for intermediate grades may be readily interpolated with sufficient accuracy when tracings are being made.

Having tabulated the uniform sections of track, as suggested on p. 184, the final speed-time curve is drawn on tracing paper, over the proper one of the two charts described. To trace the speed-time curve for any track section, move the chart under the tracing paper (with time axes coinciding) until the speed-time curve on the chart for the (equivalent) grade of the track section falls on the point of speed and time known at the beginning of that section. Trace this curve to the point where its corresponding distance-time curve indicates that the length of the track section has been covered, and repeat for the various track sections tabulated. It is advisable that the retardation portions of each run be plotted backward from the stop, as described on p. 183, and here also the same method of tracing may be used.

The final distance-time curve may also be traced from these charts, if, after the speed-time curve section has been drawn for a given track section, the chart be moved under the tracing along a vertical ordinate, keeping time axes parallel, until the proper distance-time curve coincides with the terminal point on the end of the curve as drawn for the preceding section; then trace for the proper distance.

The run curve shown in Fig. 51 was constructed by this tracing method from the charts shown in Figs. 54 and 55. In the data assumed, and given below, the breaks in grades have been made much sharper than are practicable, simply in order to bring out in a small figure the effects of changes in grade on the speed-time curve. The data assumed for Fig. 51 are as follows:

Section	Length	Grade
o–a	0.20	level
a–b	0.25	1 per cent. up
b–d	0.30	½ per cent. down
d–e	0.95	level

Braking to begin at 40 miles per hour.

Straight Line Speed-time Curves

(From A. H. Armstrong, Standard Handbook, 1910, Sec. 13, Pars. 66 to 76, inc.)

The problem of train acceleration deals with the movement of a given weight over a given distance within a specified time. As it is impracticable to start and stop the train instantaneously, it is necessary to deal with some finite rate of acceleration and braking, thus giving rise to the simple form of speed-time curves shown in Fig. 56. The speed-time curve is here shown in the simplest form, acceleration being carried on at constant rate up to the point of applying brakes, which are so applied as to also give a constant rate of braking. The area enclosed within the triangle, *A*, *B*, *C*, is proportional to the distance travelled, the distance covered up to any instant being represented by the distance-time curve shown. Thus, with the constants chosen in Fig. 56, a maximum speed of 60 miles per hour is required to obtain an average speed of 30 miles per hour that is, covering a distance of 5280 ft. in 120 seconds.

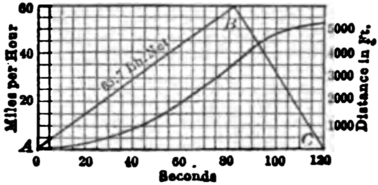


FIG. 56.—Typical straight line speed and distance curves (no coasting).

The simple formulas required in the construction of fundamental speed-time curves are given as follows:

Let s represent velocity in feet per second
f, the force producing acceleration expressed in pounds per ton
t, the time interval
m, the mass $\left(m = \frac{w}{g} = \frac{w}{32.2}\right)$, and
w, the weight in pounds.
Then

$$s = \frac{ft}{m} = \frac{ftg}{w}$$

Expressing w in tons, $s = \dfrac{32.2ft}{2000}$

Then $s = 0.0161\,ft$

It is more convenient to express velocity in miles per hour.
Hence $S = 0.682s$, in miles per hour
and substituting $S = 0.01098ft$.
the distance covered in any given time may be expressed

$$\begin{aligned} L &= \frac{ft^2}{2m} \\ &= \frac{ft^2 \times 32.2}{2 \times 2000} \\ &= 0.00805\,ft^2 \end{aligned}$$

In practical operation it is not possible to choose the rate of acceleration and braking with such nicety as shown in Fig. 56, a greater or less period of coasting being required. Introducing coasting gives rise to the form of speed-time curve shown in Fig. 57, showing three friction rates: $F = 0$, 15 and 30 lb. per ton respectively. With no friction the speed-time curve *ABCD* is constructed, the speed being maintained constant at 40 miles per hour during the coasting period. With 15 lb. per ton friction, the speed-time curve, *AEGD* is formed, and with 30 lb. per ton friction the speed-time curve *AFHD*. The introduction of friction occasions a falling off of speed during the coasting period proportional to the friction value taken, which for the sake of simplicity is here assumed to be constant at all speeds.

The speed-time curves shown in Figs. 56 and 57 both indicate the completion of the run of 5280 ft. in 120 seconds, although in one case the rate of acceleration was that produced by 65.7 lb. per ton, and in the other case by 100 lb. per ton. These curves are of equal area, as the distance in each case is 5280 ft., and it thus becomes possible to produce any number of speed-time curves for a given distance and elapsed time by varying the rate of acceleration with consequent variation in time of coasting.

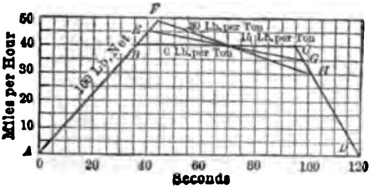


FIG. 57.—Typical straight line speed-time curves (various coasting resistances).

A more extended set of curves is given in Fig. 58, for the same distance of 1 mile covered in 120 seconds, the rate of acceleration varying from 0.713 miles per hour per second as a minimum to an infinite number of miles per hour per second as a maximum.

A train resistance value of 15 lb. per ton is assumed constant at all speeds and the dotted curve *AB* is the loci of the maximum speeds reached with the different rates of acceleration. The highest maximum speed required is obtained with no coasting, and the minimum speed is obtained with an infinite rate of acceleration. The pounds per ton corresponding to the different accelerating rates are given as including 15 lb. per ton train resistance, hence the net tractive effort values corresponding to the rates of acceleration indicated are 15 lb. per ton less than the figures given.

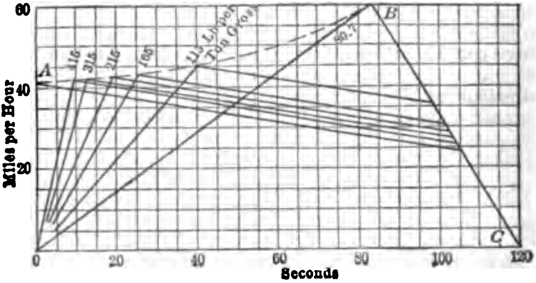


FIG. 58.—Typical straight line speed-time curves (various rates of acceleration).

Instead of plotting similar curves for distances other than 5280 ft., advantage may be taken of the fact that the area enclosed by the speed-time curve is proportional to the distance travelled and the coordinates are proportional to the square root of the enclosed area. It is convenient therefore to plot a full series of curves for one distance, preferably one stop per mile, that is, a distance of 5280 ft. run, and apply the results so obtained for any other distance by using a factor expressing the relation of the square roots of the distance traveled. This is shown in Fig. 59, where *ABCD* represents an area of 1 mile, or one stop per mile *AFIL* two stops per mile with a factor of $\frac{1}{\sqrt{2}} = 0.707$; *AEHK* four stops per mile with a factor of $\frac{1}{\sqrt{4}} = 0.5$, and *AGJM* one stop in 1½ miles with a factor of $\sqrt{1.5} = 1.225$.

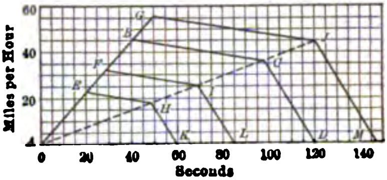


FIG. 59.—Similar straight line speed-time curves (various distances).

Referring to Fig. 58, it is obvious that a similar sheet could be prepared for any elapsed time other than 120 seconds, using the same train resistance and braking values of 15 and 150 lb. per ton respectively.

Fig. 60 is constructed to show the time limits imposed by 15 lb. per ton train resistance, and 150 lb. per ton braking for any length of run and any rate of acceleration. The dotted curves indicate the loci of the several maximum speeds reached with different accelerating rates for a run made in a given elapsed time; thus the dotted curve terminating at 80.7 lb. per ton is a reproduction of the similar dotted curve, *AB*, given in Fig. 58, and gives the maximum speed reached with any rate of acceleration for a run of 5280 ft. in 120 seconds with 15 lb. per ton train resistance and 150 lb. braking effort. Similarly, the dotted curve terminating at 100.4 lb. per ton gives the

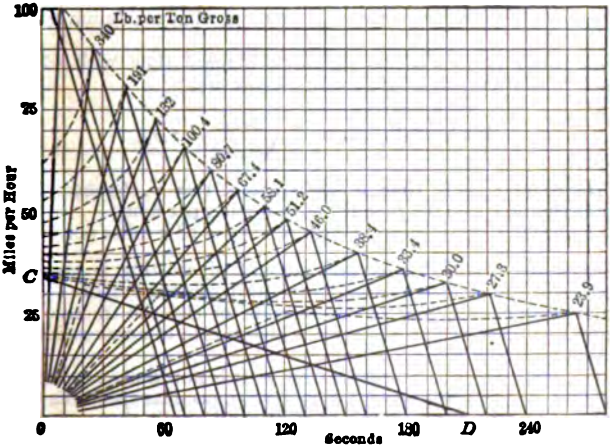


FIG. 60.—General straight line speed-time curves (train resistance, 15 lb. per ton; braking resistance, 150 lb. per ton).

limiting maximum speeds reached with any rate of acceleration when a run of 5280 ft. is accomplished in 110 seconds with the same values of train resistance and braking, etc.

The full line *CD* gives the angle made by a coasting line at the rate of 15 lb. per ton train friction. Thus in a run completed in 120 seconds, the minimum accelerating rate corresponds to 80.7 lb. per ton (gross) and no coasting is introduced, braking commencing as soon as acceleration ceases. If a higher rate of acceleration than 80.7 lb. per ton be used for a cycle completed in 120 seconds, for example 132 lb. per ton (gross), coasting must be introduced between the accelerating and braking lines. This coasting line my be plotted, with 132 lb. per ton acceleration,, by drawing a line parallel to full line *CD* (Fig. 60) starting at intersection of accelerating line, 132 lb. per ton and dotted line to 80.7, and terminating at intersection with braking line ending at 120 seconds.

By the use of Fig. 60 it becomes possible to determine the time required to make a run over any distance with any rate of acceleration, provided the train resistance is 15 lb. per ton and braking corresponds to 150 lb. per ton retarding effort.

Example: Given a distance of 8000 ft., train resistance 15 lb. per ton, braking effort 150 lb. per ton, tractive effort gross 67.4 lb. per ton (including 15 lb. per ton train resistance), what is the minimum time required to perform the run and what maximum speed is reached?

Solution: From Fig. 60, minimum elapsed time with 67.4 lb. tractive effort is 130 seconds with no coasting.

$$\text{Ratio of distances} = \sqrt{\frac{8000}{5280}} = 1.23.$$

Hence for 8000 ft. time of run = 130 × 1.23 = 160 seconds.
Maximum speed for 5280 ft. = 55.6 miles per hour.
Hence for 8000 ft. speed = 55.6 × 1.23 = 68.5 miles per hour.

In actual practice, a certain amount of coasting is necessary; hence, the run of 8000 ft. would be made in somewhat more than the minimum possible limit of 160 seconds, or else the tractive effort should be increased to allow for a higher rate of acceleration that would permit of some coasting.

Fig. 60 is of universal application as it is not limited to any particular type of motive power having its own peculiar speed characteristics. Moreover, the values of 15 lb. and 150 lb. chosen for train resistance and braking effort respectively are conservative operating values obtaining in practice. The maximum speed which is reached during the performance of a service run will be little influenced by the type of motive power and its curve characteristics. The values indicated in Fig. 60 will hold approximately true in service operation with series motors of either the alternating current or direct-current type, and hence, the curves given constitute a set of fundamental data by means of which it becomes possible to attack any acceleration problem and approximate the several data required.

Current-time Curves. A current-time curve is drawn to indicate the current per motor, current per car, or current per train at any instant. It is plotted between time values as abscissas and current in amperes as ordinates, and for convenience is constructed on the same time axis with the speed-time and distance-time curves. (For a typical example see Fig. 46.)

Current Curve for One Motor.

(*a*) *During the Straight Line Acceleration Period.* During absolute straight line acceleration the average value of the current will remain practically constant at the value, shown by the current-tractive effort curve for the equipment, necessary to give the required tractive effort for that rate of acceleration. While the current is being controlled the exact shape of the current curve depends upon the arrangement and number of steps of the starting rheostat, transformer, or auto-transformer, and the shape of the current-tractive effort characteristic curve for the motor equipment. At each step of increase of voltage applied under control, the value of the current is slightly higher than that to supply the tractive effort for the constant rate of acceleration desired, and this value of current decreases in accordance with the current value as shown by the current-speed curve for the motor equipment as the speed increases.

(*b*) *During Acceleration Beyond the Straight Line Acceleration Period.* From the time full voltage is applied to the motor until the current is cut off, the value of the current at any instant is given by the current-tractive effort motor characteristic curve for the proper voltage and at the speed for that instant.

Current Per Car. (Two and four motor equipments.) To plot the current per car the value of current at any instant (for similar motor equipments) is found from the value of current per motor at that instant, as follows:

(*a*) *Two Motor Equipments* (Series parallel control)
Series (current per car) = (current per motor)
Parallel (current per car) = 2 × (current per motor)

(*b*) *Four Motor Equipment*
Series (current per car) = (current per motor)
Series-parallel (current per car) = 2 × (current per motor)
Parallel (current per car) = 4 × (current per motor)

Current Per Train. In plotting the current per train having more than one motor car the value of the current per train at any instant is equal to the sum of the current for all the motor cars at that instant.

Potential Curve. The line potential at the car, or potential across motor terminals, is generally plotted between time in seconds as abscissas and volts as ordinates on the same time axis as is used for the current curve. The value of the potential at the car at any instant depends upon the potential of the generating station and substation, the regulation of the generator, the efficiency and regulation of transformation, transmission, conversion and distribution, and load on the system. Its value may be obtained practically only by test. For preliminary work an average voltage at the car is usually assumed to be constant; the corresponding curve is a straight line parallel to the axis of time.

Power and Power Factor Curves. The power curve may be plotted on the same time axis with other curves as above, and its instantaneous ordinate (usually to a scale of kilowatts) is at any point proportional to the product of potential and current per motor, car or train at that instant. In the case of alternating-current equipments, the power factor must, of course, be used in the determination of the power ordinate values, and in such cases, the power factor curve is usually also plotted on the same time axis, the instantaneous values being determined in connection with the motor characteristic curve, where the power factor of the motor is shown plotted against the current values.

Traction Power Requirements

Average value of power required by train throughout a given period of time. This is equal to the value of the total energy consumed by the train throughout that period divided by the length of that period. This may be expressed by the formula

$$P_1 = \frac{3.6e_r}{t}$$

in which P_1 = average power required by the train throughout period t, kw.

e_r = total gross traction energy consumed by train throughout period t, watt-hours. (See Energy Consumption.) If the train completes several runs during this period, e_r is equal to the total energy consumed by the train in making all those runs

t = length of period, seconds.

If the gross traction energy input to the train (e_r) has not been calculated the approximate average value of power input required by a train during a given period may be obtained by the formula:

$$P_1 = \frac{7.2FWL}{tU}$$

in which P_1 = approximate value of average power input required by the train, kw.

F = total average train, track curve and grade resistance ($f + C \pm G$) for the train throughout the period t, pounds per ton weight of train. (See Train Resistance)

W = total weight of train, tons

L = distance traveled during period t, miles

t = length of period during which the average power is to be determined, seconds

U = average efficiency of motor equipment, *decimally expressed.* If L is the actual length of a complete run then U is the efficiency of acceleration of train and motor equipment (see page 206) *decimally expressed.*

Value of power input required by train while moving at constant speed. The approximate value of power input required by a train moving at a constant speed may be obtained by the formula:

$$P_2 = \frac{2FWS}{1000U} = \frac{FWS}{500U}$$

in which P_2 = approximate value of power input required by train, kw.

S = constant speed of train, miles per hour

F = total constant train, track curve and grade resistance ($f + C \pm G$) for the train while running at speed S, pounds per ton weight of train. (See Train Resistance)

W = total weight of train, tons

U = efficiency of motor equipment at the proper speed, *decimally expressed.* This may be taken from the characteristic curve for the motor equipment.

Value of power input required by train while moving at constant speed on tangent level track. When the train is moving at a constant speed on a tangent level track C and G are zero and the formula is

$$P_2 = \frac{2fWS}{1000U} = \frac{fWS}{500U}$$

in which P_2 = approximate value of power input required by train, kw.

f = constant train resistance for the train while running at speed S, pounds per ton weight of train. (See Train Resistance)

W, S and U = same as given in paragraph immediately preceding.

Value of power input required by train at any instant during acceleration may be obtained by the formula

$$P_2 = \frac{2F_aWS}{1000U} = \frac{F_aWS}{500U}$$

in which P_2 = approximate value of power input required at that instant, kw. (except loss in control apparatus)

F_a = gross tractive effort of motors at that instant (including not only that required for acceleration, but that used in overcoming train resistance and track grade and curve resistance), pounds per ton weight of train. (See Acceleration)

W = total weight of train, tons

S = speed at that instant, miles per hour

U = efficiency of motor equipment, at a load corresponding to the required gross tractive effort per motor, *decimally expressed.*

Value of power input required by train during straight line acceleration for direct-current or single-phase equipments with rheostatic control,

$$P_4 = \frac{F_{a1}WS_1}{500U}$$

in which P_4 = approximate average of power input required during straight line acceleration, kw.

F_{a1} = gross tractive effort of motors during straight line acceleration, pounds per ton weight of train

W = total weight of train, tons

S_1 = speed at instant when rheostat is entirely cut out, miles per hour

U = efficiency of motor equipment, at a load corresponding to the required gross tractive effort per motor, *decimally expressed.*

Note that for the three cases of (1) parallel, (2) motors two in series and (3) motors four in series, the speed S should correspond to the instant when rheostat is entirely cut out with such motor combination. As a rough approximation, the power input in cases (2) and (3) are about 1/2 and 1/4, respectively, that in case (1).

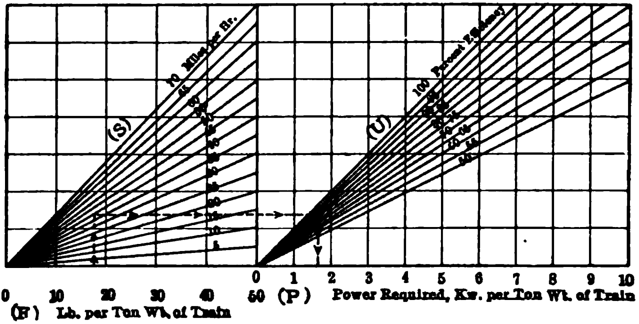


FIG. 61.—Power required per ton weight of train.

Graphical Solution of Power Equations. Figs. 61 and 62 give a general graphical solution of the equation $P = \frac{FS}{500U}$ for the amount of power required per ton weight of train. Fig. 61 is for values of F up to 50 lb. per ton. For speeds greater than 70 miles per hour use the curve for speed = $\frac{\text{(given speed)}}{\text{(a constant)}}$ and multiply the resulting kw. per ton weight of train by that constant. Fig. 62 is to be used in determining the power necessary while the train is accelerating or in other cases where the value of F is greater than 50 lb. per ton weight of train.

Graphical Determination. The average value of power required by a train during a given period of time may be determined from the power-time curve for the train. (See Power-time curves, page 196.) It is proportional to the average ordinate of the power-time curve during that period (if values of time are plotted as abscissas). This may be found from the area (conveniently determined by planimeter) and expressed in kw., it is equal to $\frac{AP}{T}$.

in which A = area under the power-time curve, square units
P = power per unit ordinate distance, kw.
T = length on time axis representing duration of period, units.
Units may be in inches, centimeters, etc., as desired, but A, P, and T must all refer to the same unit.

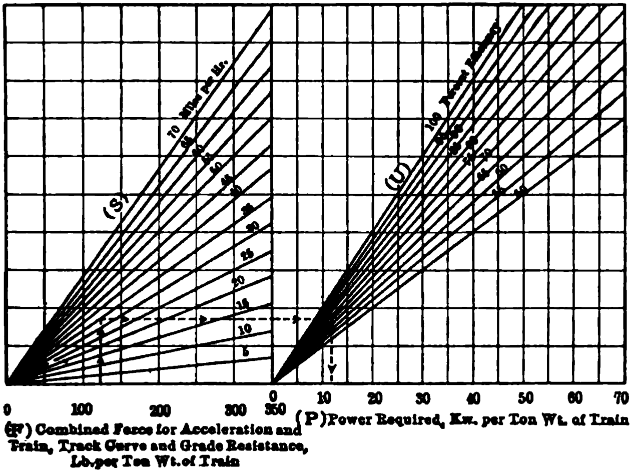


FIG. 62.—Power required per ton weight of train.

Instantaneous Value of Traction Power Required by Train. The value of traction power required by a train at any instant may be taken directly from the power-time curve for the train and run, or it may be obtained by the following formulas:

for direct current, $P_1 = \frac{I_2E}{1000}$

for single-phase alternating current $P_1 = \frac{I_2EF}{1000}$

for three-phase alternating current $P_1 = \frac{1.732 \times I_3EF}{1000} = \frac{I_3EF}{577}$

in which P_1 = instantaneous value of power required by train, kw.

I_2 = current per train at that instant, amperes

I_3 = current per train at that instant, amperes per wire of three-phase system

I_2 and I_3 may be taken from the current-time curve for the train

E = trolley or third rail electromotive force at the car at that instant, volts. This may be taken from the electromotive force-time curve for the train and run

F = power factor of train at that instant decimally expressed. This may be obtained from the power factor-time curve. (See Run Curves.)

Average Value of Traction Power Required by Several Trains During the Same Period. The average value of power required by several trains throughout a given period is equal to the sum of the average values of power required by all those trains throughout that period.

Average Value of Traction Power Required by All the Trains on a Given Section During a Given Period. The average value of power required by each train may be calculated for the time during which, and in the period given, the train is on the given section. The sum of the average power thus determined for all the trains is the average power required throughout the given period by all the trains on the given section.

Instantaneous Value of Power Required by Several Trains. The instantaneous value of power required by several trains is equal to the sum of the instantaneous values of power required by all those trains at that instant.

Power Required at Substation. The average or instantaneous value of power required at the substation bus bars is equal to the average or instantaneous value, respectively, of power required at the trains taking power from that substation divided by the average efficiency (decimally expressed) of the distribution and working conductor systems connecting the trains to the substation. In approximating the power required at a given time on a given section over which the trains have regular running times and all definite stopping places, such as turnouts and stations, the train sheet or graphical time table (see p. 137) may be used to advantage as it will give the number and location of trains on the section at any time. This information together with the run curves for the trains and runs included in this section will make possible the closest approximation to the value of power required at the substation bus bars at any instant. Where trains are not operated on regular running times with definite stopping places, so close an approximation to the value of power required at any instant is impossible, but the average value of power required during any period may be approximated to a degree of accuracy depending upon the regularity, frequency and uniformity of operation over this section. The average value of power per train required may be determined from the run curve for an average train and typical run on this section. Multiplying this average value by the number of trains on the section during the given period will give the approximate average value of power required at the substation throughout that period. Any change in the headway, speed or weight of trains will tend to change the power requirements of the given section. For sections on which such changes are brought about periodically, as in putting on extra cars and adding trailers during rush hours, the power requirements should be calculated for each of the different conditions of operation.

Power Required at Generating Station. In the operation of a system without substations the value of power required at the generating station bus bars may be determined in the manner just outlined for the determination of power required at the substation bus bars. The average or instantaneous value of power at the generating station bus bars required by a substation is equal to the corresponding average or instantaneous value, respectively, of power required at the substation bus bars divided by the combined efficiency (decimally expressed) of substation, transmission from generating station to substation and generating station transformation. The average or instantaneous value of power required at the generating station bus bars by several substations is equal to the sum of the corresponding average or instantaneous power values, respectively, required at the generating station bus bars by all the substations.

Load Curves. The load curve for a substation or generating station may be approximated by plotting the instantaneous or average values of power required at the bus bars of the station against elapsed time and connecting adjacent points so plotted. If the load curves for the substations are first constructed they may be convenient in applying the method outlined in the preceding paragraph for determining the power required at the generating station. A load curve for an existing load may be automatically drawn by a graphic recording wattmeter. A curve so drawn gives instantaneous values of power, and from it average values of power may be determined in the manner outlined for determining the average value of power required by a train.

Energy Consumption

Energy Consumption for Traction. The net energy available for traction remaining after the control, wiring, motor and mechanical transmission losses in the train have been supplied is consumed in the two following processes: first, balancing train, track grade and curve resistance; second, heating brake shoes and car wheels while braking. The first continues while the train moves, the second only while the train is in motion and brakes are applied. Therefore, the net energy consumed for traction while the train is in motion but the brakes not applied is consumed in balancing train, track grade and curve resistances, and the net energy consumed for traction while the train is in motion and the brakes are applied is consumed in balancing train resistance, track grade, track curve resistance, and heating brake shoes and car wheels.

Net Traction Energy Consumed in Moving Train when Brakes are not Applied.

$$e_F = \frac{5280 \times 745.6}{60 \times 33000} FWL$$

$$= 1.99\,FWL = \text{approximately } 2\ FWL$$

in which

e_F = energy necessary to balance train, track curve and grade resistances while the train travels the distance considered, watt-hours

F = total average train, track curve and grade reresistance $(f \pm G + C)$ for train while traveling the given section, pounds per ton weight of train

L = distance traveled, miles

W = weight of train, tons.

NOTE: Since the value of F is always an approximation, the use of 2 instead of the more nearly exact value 1.99 for the constant is justified in this and similar formulas herein.

Net Traction Energy Consumed while Train is Coasting or while Moving with Brakes Applied. The value of the total net traction energy consumed by a train in passing with power off over a section between two given points is equal to the difference between the total values of kinetic energy of the train at these two points, that is

$$E_B = E_1 - E_2$$

in which

E_B = net traction energy consumed while brakes are applied or train is coasting

E_1 = total kinetic energy of train at beginning of section considered. (See E_n below)

E_2 = total kinetic energy of train at end of section considered. (See E_n below)

E_n = $2000Wh$

in which

E_n = total kinetic energy of train at any instant n, foot-pounds

W = total weight of train, tons

h = kinetic energy head for train at the instant n, feet.

Expressing kinetic energy head in terms of velocity of train (see p. 144) and reducing E_n to watt-hours,

$$E_n = \frac{2000W \times (5280)^2 V_n^2}{32.2 \times 2 \times (3600)^2 K \times 2655.4}$$

$$= \frac{WV_n^2}{39.75\ K}$$

$$= \frac{0.0252\ WV_n^2}{K}$$

in which

E_n = total kinetic energy of train at any instant n watt-hours
V_n = velocity of train at that instant n, miles per hour
K = ratio of linear inertia to total inertia of train. (See p. 172)

Substituting E_n in the formula for E_B,

$$E_B = \frac{WV_1^2}{39.75\,K} - \frac{WV_2^2}{39.75\,K}$$

$$= \frac{W}{39.75\,K}(V_1^2 - V_2^2) \text{ or } = \frac{0.252\,W}{K}(V_1^2 - V_2^2)$$

in which

W = total weight of train, tons
V_1 = velocity of train at first point (beginning of section considered), miles per hour
V_2 = velocity of train at second point (end of section considered), miles per hour.

Net Traction Energy Consumed in Heating Brake-shoes and Car Wheels during the Process of Braking.

$$E_b = E_B - e_F$$

$$= \frac{W}{39.75K}(V_3^2 - V_4^2) - 2\,WFL_b$$

$$\text{or} \quad = \frac{0.0252\,W}{K}(V_3^2 - V_4^2) - 2\,WFL_b$$

in which

W = total weight of train, tons
K = ratio of linear inertia to total inertia. (See p. 172)
V_3 = velocity of train at beginning of braking section considered, miles per hour
V_4 = velocity of train at end of braking section considered, miles per hour. When train is brought to a standstill by braking, V_4 becomes zero
L_b = length of braking section, miles
F = total average train, track curve and grade resistance ($f \pm G + C$) for train while traveling the braking section, pounds per ton weight of train.

Approximate Formula for Energy Consumed in Heating Brake-shoes and Car Wheels in the Process of Braking. In making a rough estimate it is often assumed that while the brakes are being applied the kinetic energy of rotation of the rotating parts just balances the train resistance, track curve, and grade resistances (if the latter be small). This assumption gives rise to the following approximate formula:

$$E_b = \frac{W}{40}(V_3^2 - V_4^2) \text{ or } 0.025W\,(V_3^2 - V_4^2)$$

When brakes are applied until train comes to a standstill, the formula becomes $E_b = \frac{WV_3^2}{40}$ or 0.025 WV_3^2 in which the significance of the symbols is the same as in the preceding paragraph. Fig. 63 gives a graphical solution of this formula.

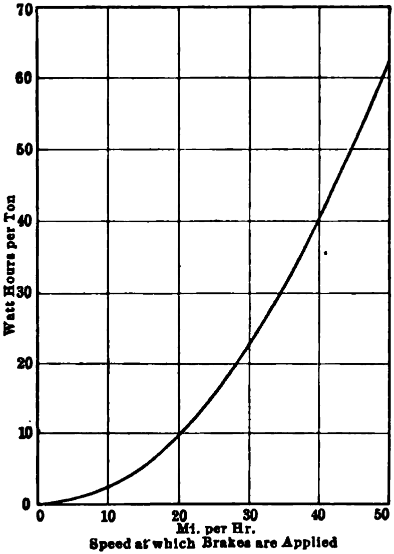


Fig. 63.—Losses in braking.

Total Net Traction Energy that must be Available for Traction while Train is Running with Power on Between Two Points. The value of this energy is equal to the sum obtained by adding the difference between the values of the kinetic energy of the train at these two points to the net traction energy consumed by the train in passing between the two points. It is expressed by the following formula:

$$
\begin{aligned}
e_p &= \frac{W}{39.75K}(V_6^2 - V_5^2) + 2\,WF_2L_2 \\
&= \frac{0.0252W}{K}(V_6^2 - V_5^2) + 2\,WF_2L_2
\end{aligned}
$$

in which

W = total weight of train, tons
K = ratio of linear inertia to total inertia of train. (See p. 172)
V_5 = the velocity of the train at the beginning of the section over which the train is considered to run with power on, miles per hour. The value of V_5 is zero if train starts from rest at this point
V_6 = the velocity of the train at the end of the section over which the train is considered to run with power on, miles per hour
F_2 = total average train, track curve and grade resistance $(f \pm G + C)$ for train while traveling the section between the two given points, pounds per ton weight of train
L_2 = length of section between the two given points, miles. This is the length considered over which the train runs with power on.

Total Net Traction Energy Consumed during any Run.

Case 1. Train coasts to standstill, brakes not applied.

$$\text{Energy consumed} = e_F \quad \text{(See p. 202.)}$$

Case 2. Brakes applied during any part or number of parts of run.

$$\text{Energy consumed, kilowatt hours} = e_F + E_B$$

in which

e_F = energy consumed while brakes are *not* applied, kilowatt hours. (See p. 202.)

Where several sections over which the train runs without braking occur during the run, e_F is calculated for each of these sections and these values of e_F are added together to give the value of e_F for use in this formula.

E_B = energy consumed while the brakes are applied, kilowatt hours.

Where several sections over which the train runs with brakes applied occur during the run, E_B is calculated for each of these sections (see p. 202) and all those values of E_B are added together to give the value of E_B.

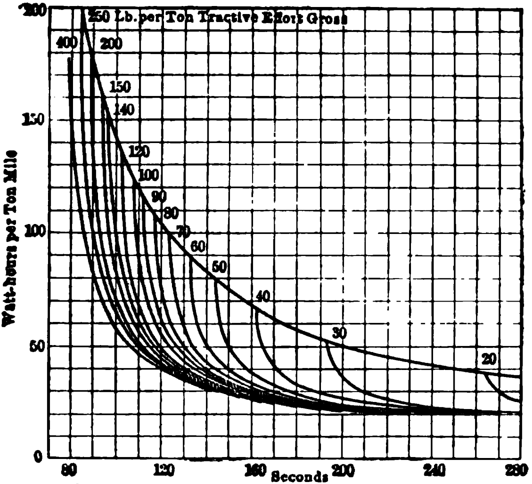


FIG. 64.—General energy output chart (train resistance, 10 lb. per ton).

General Energy Output Chart. The general energy consumption charts, Figs. 64 and 65 are from the Standard Handbookand are based on speed-time curves in Fig. 60. A constant braking rate of 150 lb. per ton weight of train is assumed in both, and a constant train resistance of 10 and 15 lb. per ton weight of train is used in the curves of Figs. 64 and 65 respectively. These curves give approximate values of energy *output* watt hours per ton mile, for a 1-mile run at various gross tractive efforts for acceleration and times required to make the run and these values must be divided by the efficiency of acceleration, to get energy input.

Use of General Energy Output Chart for Runs other than 1 Mile Long. In using the general energy output charts the chart constructed on the assumed value of train resistance should first be selected. Then the approximate value of watt hours per ton mile is given by the ordinate of the point on the proper gross tractive effort curve, whose abscissa is equal to T_1 in the following formula. The curve selected should correspond to the gross tractive effort during straight line acceleration.

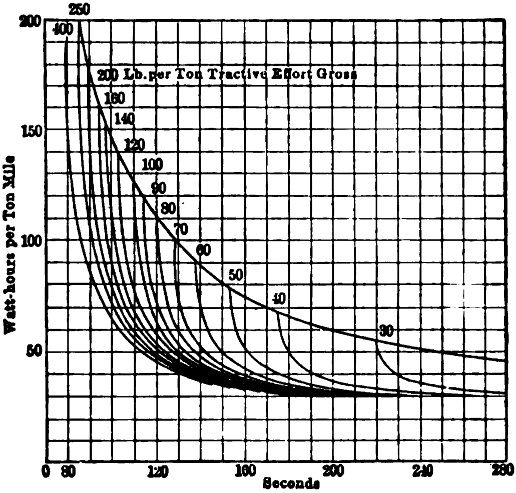


FIG. 65.—General energy output chart (train resistance, 15 lb. per ton).

$$T_1 = \frac{T}{\sqrt{L}}$$

in which

T = time to make run under consideration, seconds
L = length of run under consideration, miles.

Efficiency of Acceleration. The efficiency of acceleration of the train is the ratio of the value of the net energy available for traction (output) to the value of the gross energy delivered to the train in furnishing that net energy. It is usually expressed as a per cent. It depends upon the efficiency of control, efficiency of car wiring, motor efficiency, efficiency of mechanical transmission, and the "per cent. of straight line acceleration" (see below) *obtaining during the particular run under consideration.*

Efficiency of Acceleration with Series Motors and Three-phase Induction Motors. The following table from data given in the

Standard Handbook gives the per cent. efficiency of acceleration at various per cents. straight line acceleration for direct-current series motors, also for three-phase induction motors (connected in parallel).

Per cent. straight line acceleration	Rheostatic control per cent.	Series parallel, per cent.	Four series, two series, parallel, per cent.	Three-phase induction motors parallel, per cent.
100	43	56.0	60.5	40
90	46	59.0	62.5	43
80	49	62.0	65.0	46
70	52	64.0	67.0	49
60	56	67.0	69.0	52
50	58	69.0	71.0	55
40	62	71.0	72.5	58
30	65	72.5	73.5	61
20	68	73.5	74.0	64
10	72	74.5	74.5	72
0	75	75.0	75.0	75

Efficiency of Acceleration with Single-phase Commutating Motor Equipments. The efficiency of acceleration for trains equipped with single-phase commutating motors may be taken at 70 to 75 per cent. This value is a close approximation for the class of service to which such equipments are most often used, *i.e.*, an express or semi-express service on private right of way, with necessarily small per cent. of straight line acceleration.

EFFICIENCY OF ACCELERATION, SUBURBAN PASSENGER SERVICE. SERIES MOTORS, SERIES PARALLEL CONTROL

Description of train: 2 motor cars plus the following number of trailers	Length of run, feet	Total weight of train, tons	Average speed, miles per hour	Watt hours per ton mile		Efficiency of acceleration, per cent.
				Output	Input	
0	5360	71.5	34.6	79.8	130.0	61.5
1	5350	94.5	33.1	75.3	112.8	66.7
2	5490	118.5	32.0	69.6	99.6	69.9
3	5370	148.5	30.6	68.0	90.2	75.3
4	5380	175.5	29.8	63.8	84.9	75.3
5	5380	201.5	28.6	61.0	82.0	74.3
6	5380	228.5	27.2	59.1	79.0	74.0

(From results of experimental tests at Schenectady, N. Y., Paper by Arnold and Potter, A.I.E.E., 1902.)

The electrical equipment of each of the two motor cars consisted of four "GE-55" motors and type "M" Control.

Per Cent. Straight Line Acceleration. The per cent. straight line acceleration of a train on a given run is the ratio of the time during which the individual motors of the train take constant current to the total time current is supplied to the motors, expressed in per cent. The per cent. straight line acceleration for runs of greater than a mile in length may be less than 10; on shorter runs it is greater and may even exceed 75 for very short runs. It may be taken directly from the speed-time curves for any particular case. The per cent. straight line acceleration on the Manhattan Elevated system, N. Y., is approximately 38. This is for a 154-ton train on a 1768-ft. run, rate of straight line acceleration 1.33 miles per hour per second, maximum speed about 25.5 miles per hour, average speed 18.3 miles per hour.

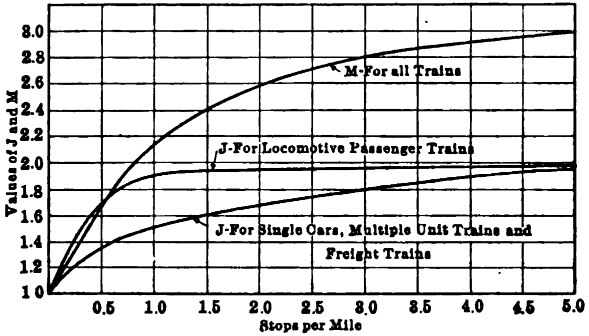


FIG. 66.—Empirical constants for energy approximation (Del Mar-Woodbury).

Approximate Determination of Energy Consumption. The following method and constants for determining the approximate amount of energy consumed in train movement are by Messrs. W. A. Del Mar and D. C. Woodbury.

Significance of symbols:

V = average running speed, excluding stops, miles per hour
V_m = maximum speed, miles per hour
L = distance between stops, miles
L_p = distance traveled with power on, miles
$N = \frac{1}{L}$ = number of stops per mile including one terminal
f = average train resistance, in pounds per ton (say that corresponding to a speed of 10 to 20 per cent. greater than the average speed)
G = average equivalent grade, per cent.
D = average curvature, degrees
U = average motor and controller efficiencies as a decimal, which is usually about 0.7
$J = \frac{V_m}{V}$ (see Fig. 66)
$M = \frac{L}{L_p}$ (see Fig. 66).

The average equivalent grade, in per cent., may be obtained by the following formula, which assumes only one-half the gravitational energy on down grades to be saved, the remainder being consumed in braking. Other assumptions may be found necessary in certain cases:

$$G = \frac{100}{l}(H_1 - \tfrac{1}{2}H_2)$$

where

l = distance between stops, feet = $5280L$
H_1 = summation of rises, feet
H_2 = summation of falls, feet.

Output at Wheel Rim and Input to Car in Watt Hours per Ton Mile

	Actual energy output at wheel rims of cars	Approximate electrical energy input to cars
Due to kinetic energy.......	$\frac{V_m^2}{36.2L}$	$\frac{J^2NV^2}{25}$
Due to train resistance......	$\frac{1.99fL_p}{L}$	$\frac{2.85f}{M}$
Due to grades.............	$\frac{39.8GL_p}{L}$	$\frac{57G}{M}$
Due to curves.............	$\frac{1.99DL_p}{L}$	$\frac{2.85f}{M}$
Total.................	Sum of above	Sum of above

In this table the first column gives the approximate mechanical energy required at the wheel rims. In the second column an allowance of 70 per cent. for efficiency of motors, gears and control has been made. (For values of J and M see Fig. 66.) In cases where V_m and L_p are known, more accurate results can be obtained by using them in the formula of the first column.

Example: A multiple-unit train makes an average speed, while running, of 30 miles per hour, making a stop every 2 miles. The average train resistance is 7 lb. per ton, the average equivalent grade 0.05 per cent. and the average curvature 0.75 deg.

Then $V = 30$
$f = 7$
$G = 0.05$
$D = 0.75$
$N = 0.5$

$$\left.\begin{aligned} J &= 1.36 \\ M &= 1.67 \end{aligned}\right\}\text{from Fig. 66}$$

Watt hours per ton mile

Then,

$$\text{Kinetic energy} = \frac{1.36^2 \times 0.5 \times 30^2}{25} = 33.3$$

$$\text{Train resistance energy} = \frac{2.85 \times 7}{1.67} = 12.0$$

Energy for grades $= \dfrac{57 \times 0.05}{1.67} = 1.7$

Energy for curves $= \dfrac{2.85 \times 0.75}{1.67} = 1.3$

Total energy input at train $= 48.3$

Energy Consumed in Rheostat. The energy consumed in the series motor control rheostat and appearing as heat therein depends upon (1) the voltage drop across the rheostat, (2) the current flowing through the rheostat and (3) the time during which this current continues to flow.

Below are given approximate formulas for calculating the energy consumed in the series motor control rheostat per motor during start. To approximate the energy consumed in the series motor control rheostats for the whole train the rheostat energy consumption per motor should be calculated for all motors and these should be added together. Cases 1 to 3, inclusive, are for equipments arranged to give a uniform rate of straight line acceleration. Case 4 is for equipments arranged to give two rates of acceleration, viz., one rate of acceleration while half the motors are in series with the other half, and another rate of acceleration while all the motors are in parallel. (See p. 173.) The condition of constant current during the straight line acceleration period is more or less closely approximated in operation. Since the resistance is arranged in steps, each of a finite value, the value of the current will fluctuate above and below this constant as the controller is advanced and the motor speeds up. When the train acceleration approximates a constant rate (straight line), the mean of these fluctuating values of current will approximate the value of current necessary to accelerate the train at the constant rate. For convenience in using these formulas, they are given for rheostat energy consumption *per motor*. The second formula under Case 2 is an exception. It gives an approximation to the loss per ton weight of train.

Significance of Symbols, Cases 1 to 3, Inclusive.

e_R = energy consumed in rheostat during straight line acceleration period, watt hours per motor

T = duration of straight line acceleration, seconds. This may be taken from the speed-time curve for the particular train and run under consideration

I_m = constant current *per motor* during period of straight line acceleration, amperes. This may be taken from the current-time curve per motor for the particular train and run under consideration

E = working conductor (trolley or third rail) potential at the motor car or locomotive, volts

R_m = resistance of the motor, ohms. (See Fig. 47, p. 264.)

Case 1. One or more motors, rheostatic control. All motors in parallel throughout straight line acceleration period.

$$e_R = \frac{I_m T (E - I_m R_m)}{2 \times 3600}$$

Case 2. Two- and four-motor equipments, series-parallel. Two-motor equipments having motors in series throughout first part of straight line acceleration period and in parallel throughout the remainder of straight line acceleration period. Four-motor equipments having two groups of two motors in parallel in series throughout the first part of the straight line acceleration period and all motors in parallel throughout the remainder of the straight line acceleration period.

$$e_R = \frac{I_m\,T\,(E^2 - 2\,EI_m\,R_m + 2\,I_m^2\,R_m^2)}{4 \times 3600\,(E - I_m\,R_m)}$$

$$L = \frac{AVT}{3600\,W}$$

in which L = approximate loss in watt-hours per ton, A = amperes per car with series position of controller, V = ½ line volts − drop in motor, T = time of straight line acceleration in seconds, and W = weight of car in tons.

Case 3. Four motors, series, series-parallel, parallel. All motors in series throughout first part of straight line acceleration period, two groups of two motors in parallel in series throughout the second part, and all motors in parallel throughout the remainder of the straight line acceleration period.

$$e_R = \frac{I_mT\,(3\,E^2 - 4\,EI_mR_m + 8\,I_m^2R_m^2)}{16 \times 3600\,(E - I_mR_m)}$$

Case 4. Two rates of straight line acceleration (see p. 173), i.e., two values of constant current per motor during straight line acceleration.

Significance of Symbols, Case 4.

e_R = energy consumed in rheostat during straight line acceleration period, watt hours per motor

T_1 = duration of first rate of straight line acceleration, seconds. (Series connection)

T_2 = duration of second rate of straight line acceleration, seconds. (Parallel connection.) (T_1 and T_2 may be taken from the speed-time curve for the train and run under consideration)

I_1 = constant current *per motor* during period (T_1) of first rate of straight line acceleration, amperes. (Series connection)

I_2 = constant current *per motor* during period (T_2) of second rate of straight line acceleration, amperes (parallel connection). (I_1 and I_2 may be taken from the current-time curve (per motor) for the particular train and run under consideration)

E = working conductor (trolley or third rail) potential at the motor car or locomotive, volts

R_m = resistance of the motor, ohms. (See Fig. 47, page 264.)

Case 4. Two- and four-motor equipments, series-parallel. Two-motor equipments having motors in series throughout period T_1 and in parallel throughout period T_2. Four-motor equipments having two groups of two motors in parallel in series throughout period T_1 and all motors in parallel throughout period T_2.

$$e_R = \frac{I_1T_1\,(E - 2\,I_1R_m) + I_2T_2E}{4 \times 3600}$$

Energy Consumption Reduced by Use of Grade at Approach to Station. A considerable saving of energy may be brought about by causing a train to lift itself, at a station, to an elevation greater than its elevation between stations. By this process much of the energy that would be dissipated as heat in brake-shoes and car wheels in bringing the train to a stop while maintaining a practical schedule speed on a level track is converted into potential energy available to aid in accelerating the train while it departs from the station. This method of conserving energy is especially applicable to operation on elevated railways and subways, where the track grades are to a greater extent under the control of the engineer than is generally the case with the surface railway. Fig. 67 (hypothetical example by P. A. Bancel, A.I.E.E., 1910) shows the speed-time curve and energy consumption curve for a 154-ton train on a typical average run of the Manhattan Elevated system, N. Y., and the corresponding curves for the same train, with lighter motors as explained further on, running the same distance on a track having a 3 per cent. up grade at the approach to the station, and having a 3 per cent. down grade at the departure from the station. It is to be noted that the train operates at the same schedule speed in both cases, but in traversing the run having the grades it consumes much less energy than it does in traversing the all level run. The rate of straight line acceleration is the same in both cases. In this example, the 3 per cent. grade at departure from the station furnishes a force of approximately 9240 lb. of the 18,620 lb. (if we neglect rotational inertia) necessary to accelerate the train at the required rate of 1.33 miles per hour per second. The motors are then called upon to furnish an accelerating force of approximately 18,620 − 9240 = 9380 lb. or about half that necessary on the all level run so they need have only about 50 per cent.

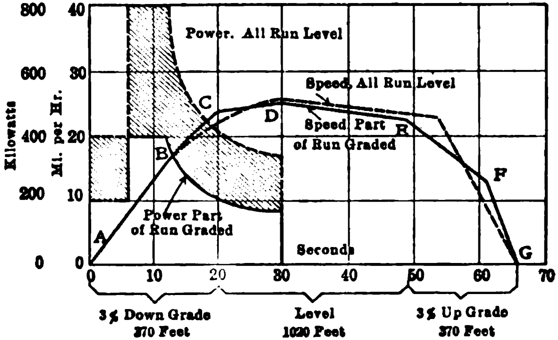


FIG. 67.—Example of energy saving by use of grades at station stops.

the capacity required for the all level run. In constructing the power curve, Fig. 67, for the train operating on the run having the grades, it was assumed that the capacity of the motors and consequently their torque at any speed are one-half those for the all level run. A comparison of the power-time areas indicates that in this case operation on the run having the grades demands only about half the energy necessary for operation on the all level run.

Energy Consumption Reduced by Train Operation. The following comparative data are from the report of the Joint Committee on Transportation-Engineering, Am. El. Ry. Eng. Assn., 1914. The values were secured on a typical interurban road in the Middle West, operating on single phase alternating current, transmission voltage 33,000, trolley voltage 6600, static transformer substations so situated that the heaviest trains cause only a very moderate line drop. Results would be similar on any interurban road operated on either direct or alternating current and having car equipments and feeders designed for heavy service. A normal day is compared with a holiday, the total number of trains operated each day being the same. On the holiday sufficient trail cars and motor cars were added to the various trains to take care of the traffic presented, most additions to trains being trail cars.

	Normal day	Holiday
Number of trains operated	100 per cent.	100 per cent.
Total seating capacity	100 per cent.	258 per cent.
Total ton miles handled	100 per cent.	222 per cent.
Output of power station	100 per cent.	176 per cent.
Energy consumption per ton mile	100 per cent.	77.5 per cent.

Note that everything on a normal day is taken as 100 per cent.

From the above it is readily seen what a great saving in energy consumed per car mile or per passenger mile can result from train operation. In this case the seating capacity was increased 158 per cent., total ton miles handled increased 122 per cent., with an increase in energy consumption of only 76 per cent.

Regeneration of Electrical Energy. Regeneration has been practised in ordinary braking but the savings brought about by it have been most generally considered to be insufficient to pay for the additional necessary apparatus, complications and difference in operation. Practice has, consequently, limited its application to track sections of long heavy grades. On grades ordinarily encountered where no braking is necessary the results of operation with the train running free are more satisfactory than the results that would be brought about by regeneration and its attending speed restrictions. When, however, the force of a train while it descends a grade exceeds the amount that can be utilized directly mechanically to overcome train friction, regeneration may be considered. On long mountain grades, the electrical saving by regeneration may be incidental to the saving and safety gained in avoiding the stresses that would be set up in the rolling stock in the process of mechanical braking; it may, nevertheless, be great in itself. In connection with operation on heavy grades, Mr. A. H. Armstrong (A.I.E.E., 1907) states that the amount of energy saved by regeneration may, in certain installations, amount to as great a percentage of the total as is the saving affected in coal expenditure in steam locomotives by compounding and providing superheaters and feed water heaters. In a paper by Messrs. L. B. Stillwell and H. St. Clair Putnam (A.I.E.E., 1907) it is stated that by regeneration the increase in energy consumption due to hauling a train up grade is reduced approximately 60 per cent. over a 1.5 per cent. grade, and in freight service over mountain grades the energy required will not exceed that consumed on level track by more than from 40 to 60 per cent. and it will not be doubled on grades of less than 3 per cent. in passenger service, nor less than 2 per cent. in freight service.

In order that a train may regenerate energy there must be energy consuming apparatus connected to the system to which this regenerated energy is to be supplied. This condition is generally satisfied by the presence of energy consuming trains on the line. The efficiency of the system in consuming this regenerated energy will depend upon the efficiency of transmission and distribution that connect the regenerating and the consuming apparatus, therefore, greatest efficiency is attained when regenerating and consuming apparatus are closest together, and the ideal condition is reached when one train is ascending the grade while another is descending. When this occurs, a part of the energy required by the ascending train is supplied by the descending regenerating train; thus the power house is not called upon to furnish this part. Mr. Cary T. Hutchinson has said (A.I.E.E., 1907): "Two tons going down the grade will pull 1 ton up the grade."

On the general subject of regeneration control, Mr. A. H. Armstrong (Standard Handbook) says: "It is necessary to consider the first cost of the equipment and the increased cost of maintenance as offsetting advantages derived from a possible smaller energy consumption of the car. It is not too much to expect that the car equipment will be increased fully 50 per cent. in weight and first cost if regenerative control be adopted, and the possible 15 to 20 per cent. energy must be balanced against the interest on the additional first cost and cost of maintaining the equipment."

Regeneration with Three-phase Equipment. Regeneration with three-phase induction motor equipments is automatic. No change in connections is necessary for regeneration and the speed of the train in descending a grade is but little greater than its speed in ascending the grade, the difference being the sum of the slip while operating as a generator and that while operating as a motor.

Regeneration with Series Motors. Regeneration with series motors is not automatic. It requires a means of maintaining the electromotive force of regeneration at a proper amount above the electromotive force at the motor due to trolley or third rail electromotive force. This calls for a modification of the control system. With direct-current series motors this regulation is brought about by controlling the electromotive force of regeneration. With single-phase series motors it is brought about by controlling both the electromotive force regeneration and the electromotive force at the motor due to trolley or third rail. One motor having its field excited by current from the transformer is used as the exciter for the fields of the other motors whose armatures are connected to the transformer. The connections of the motors to the transformer are arranged to give a sufficient excess of electromotive force of regeneration over the electromotive force due to third rail or trolley.

Energy Consumption in Practice. In addition to data shown elsewhere (see the general index), the following are results from a number of electric car tests in various typical services as noted.

NET TRACTION ENERGY REQUIRED PER SEAT MILE, SUBURBAN SERVICE, STEAM AND ELECTRICITY

(From results of experimental tests at Schenectady, N. Y., Arnold and Potter, A.I.E.E., 1902.)

Number of cars in train*	Length of run, feet	Average speed, miles per hour	Total weight of train, tons		Net energy required per passenger mile, watt hours	
			Steam	Electric	Steam	Electricity
1	5360	34.6	130	35.7	185.0	44.6
2	5360	34.6	154	71.5	101.5	44.6
3	5350	33.1	184	94.5	76.4	37.0
4	5490	32.0	211	118.5	55.4	32.2
5	5370	30.6	237	148.5	51.4	31.5
6	5380	29.8	264	175.5	43.1	29.2

In making the above calculations, a capacity of 65 passengers per car was used.

Suburban Service. The set of tests as shown below was on suburban lines in New England, the cars being equipped with four 40-h.p. motors:

Weight of car, pounds	42,090	42,090	42,700	42,090
Length of run, miles	15.26	25.72	16.68	35.38
Schedule speed, inc. stops, miles per hour	10.10	9.25	10.60	14.04
Average speed, exc. stops, miles per hour	12.65	12.50	12.60	16.40
Average stops per mile	4.78	5.72	3.06	2.48
Average voltage during run	460.00	480.00	480.00	488.00
Kilowatt hours per car mile at car	2.94	3.63	3.54	2.92
Kilowatt hours per car mile at power station	3.67	4.54	4.23	3.59
Watt hours per ton mile at car	140.00	173.00	166.00	139.00
Watt hours per ton mile at power station	175.00	216.00	199.00	171.00
Max. starting current per car, amp	320.00	300.00	350.00	330.00
Average starting current per car, amp	177.00	209.00	221.00	222.00

Interurban Service. The following test on a typical New England interurban railway is divided into three sections, the first and last being in the terminal cities. The car weighed 53,000 lb. and was equipped with four 50-h.p. motors:

Length of run, miles	3.06	31.16	3.83
Average stops per mile	1.62	0.80	3.92
Schedule speed, inc. stops, miles per hour	12.80	22.20	12.10
Kilowatt hours per car mile	3.14	2.48	3.50
Watt hours per ton mile	118.00	94.00	132.00

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* One-car electric train consisted of one motor car. Two-car electric train consisted of two motor cars. Electric trains of more than two cars consisted of two motor cars plus trailers to make the total number of cars given in the table.

In all cases of the steam train, the cars were hauled by a 107-ton steam locomotive designed for a high rate of acceleration.

City Service. Watt-hour meter readings were taken in Cleveland on thirteen types of interurban cars and thirteen types of city cars. The weights and energy consumption (in city service) were as follows:

	Maximum	Minimum	Average
Interurban cars, weight, pounds	77,320.00	50,840.00	59,300.00
Interurban cars, kilowatt hours per car mile	4.55	2.15	2.90
Interurban cars, watt hours per ton mile	133.00	75.00	91.50
City cars, weight, pounds	46,580.00	27,700.00	37,800.00
City cars, kilowatt hours per car mile	4.65	1.87	2.85
City cars, watt hours per ton mile	182.00	52.00	126.60

Low Floor Center Entrance Car. (Elec. Ry. Journal, 1912.) During an eight-day test of the Pittsburg low floor car on one line, the average energy consumption was 139 watt hours per ton mile at a schedule speed of 9.52 miles per hour and averaging 7 stops per mile. On another line the energy consumption by the same car was 125.8 watt hours per ton mile at a schedule speed of 9.72 miles per hour and averaging 6.4 stops per mile.

High-speed Interurban Service. In typical Indiana interurban service, with cars weighing 30 to 35 tons, watt hour meter readings for an entire month on several cars show 80 to 90 watt hours per ton mile in local service where stops average one per mile, and about 65 watt hours in "limited" service where stops average one in 4 miles. These figures include all service including switching around car houses. In these tests the four motor cars used about 6 per cent. more energy per ton mile than the two motor cars in the same service.

Gravel Train Service. In a series of tests in gravel train work with a 15-ton motor car and eight gravel cars weighing 2½ tons each empty and 11 tons each loaded, and with hauls ranging from 1.33 to 10.42 miles, the energy consumption ranged from 30 to 40 watt hours per ton mile for a loaded train and from 70 to 130 watt hours per ton mile for an empty train.

Energy Consumed in Steam Passenger Service. The following values of energy consumption in operation by steam were calculated from the results of tests on the New York, New Haven and Hartford Railroad by Mr. W. S. Murray (A.I.E.E., 1907).

Steam Express Passenger Service: 34.9 watt hours per ton mile, indicated.

Steam Local Express Passenger Service: 51.3 watt hours per ton mile, indicated.

These results are from the following:

	Express passenger service	Local express passenger service
Mileage of locomotive in 18 days	2,559.0	2,623.0
Average weight of train, tons, including locomotive and passengers	527.1	314.2
Total horse-power hours for 18 days of locomotive in revenue service based on average horse-power between Woodlawn and New Haven.	63,125.0	56,800.0

Conditions of Test. "The zone over which the test was conducted was the New York division of the N. Y., N. H. & H. R. R. Co. and all train runs had specified terminals within the zone, the mileages of which are measured." "The engines and cars included in the test were in the regular log of the mechanical superintendent of car service, with measured weights." A continuous set of indicator diagrams was taken for the runs between Woodlawn and New Haven. In this process six diagrams, 10 seconds apart, were taken on each end of one cylinder in a period of 2 minutes out of every three. Locomotives used:

	Number of locomotive	Year built	Type
Express passenger service...........	832	1905	K-4-A
	841	1905	G-4-A
Local express passenger service......	1258	1903	A-1
	1262	1903	A-1
	1271	1896	A-1
	1272	1896	A-1
	1574	1893	C-15-A

Relation between Conditions of Train Operation and Energy Consumption. Figs. 68, 69 and 70 from a paper by E. H. Anderson before the Am. El. Ry. Eng. Assn., Oct. 16, 1906, are typical curves showing the relation between length of run, accelerating force and schedule speed, respectively, and energy consumption. These curves were constructed for one single truck car equipped with two GE-70 motors operating on tangent level track at an assumed train resistance of 20 lb. per ton.

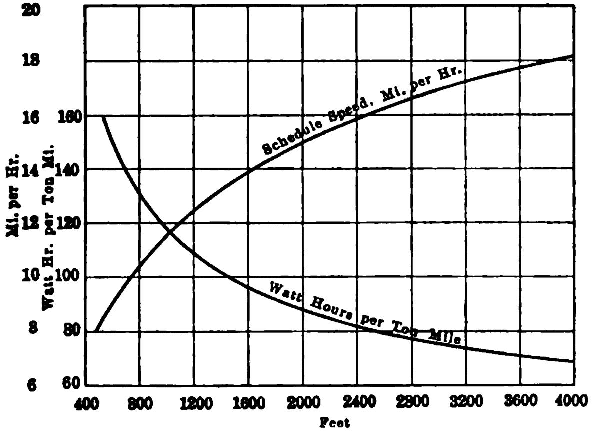

FIG. 68.—Example of relation between length of run and energy consumption.

Electric Car Tests—Methods. Special tests of electric car or locomotive equipment may be made from time to time for the purpose of obtaining data for use in one of a number of ways: to determine the adequacy of motor equipment, to determine whether or not the proper gear ratio is being employed, to check the proportion of resistance taps on the controller, to determine the possible schedule speed with a given equipment, to check trolley feeders or to aid in the design of additional feeder, etc. Depending upon the purpose for which the test is to be made, the apparatus used and readings taken will vary, but will probably include many if not all of the following:

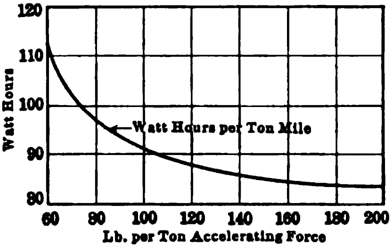

FIG. 69.—Example of relation between accelerating force and energy consumption.

Continuous Instantaneous Readings:

Voltage on line
Current per car
Voltage, one motor
Current, one motor
Speed of car
Power factor }
Watts input } (on alternating-current equipments)
Time at passing frequent landmarks such as numbered poles
Time, duration and location of all stops
Time of various controller movements
Time of application and release of brakes

Readings at beginning and end of test, and at intervals during test:

Watt hours, meter in motor circuit
Watt hours, meter in auxiliary circuits
Watt hours, meter connected for field loss
Temperature, by thermometer, of motor commutator, armature and field
Temperature of motor armature and field by drop of potential.

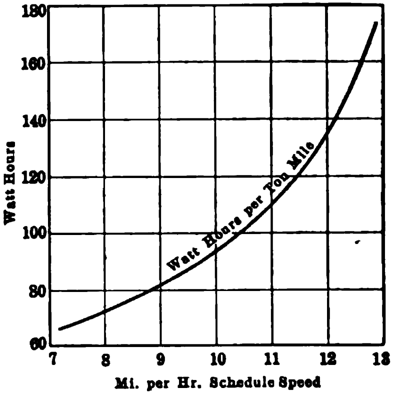

FIG. 70.—Example of relation between schedule speed and energy consumption.

The electrical readings of current, voltage, etc., should be made on instruments which are as "dead beat" as possible so that the motion of the car will affect the position of the instrument pointer to a minimum extent. If readings are to be taken from indicating instruments, there should be one observer for each instrument, together with a time observer who should give signals by means of a bell or whistle at intervals of from 2 to 10 seconds, depending upon conditions, and all instruments should be read and readings noted simultaneously at each signal. Readings should be noted on previously prepared paper with each reading consecutively numbered and at least once in each ten readings one of the observers should call out the number of the reading, so that the instantaneous readings may be consistently compared. The speed of a car may be read by means of a mechanical tachometer or perhaps preferably from an electrical tachometer in which a small direct-current magneto generator is belted, geared or connected by flexible shaft to the car axle and calibrated in volts per mile per hour. The exact time should be noted at passing frequent landmarks, such as numbered poles, so that in the later working up of results profiles and maps may be consulted to determine at what points the car encountered curves and grades. Readings of watt-hour meters should be taken at beginning and end of tests and also at such points where the schedule speed or general profile of the line materially change. It is sometimes convenient to connect in a specially calibrated watt-hour meter with the current from one motor through the series coils and the potential coils connected across a field of the same motor. This watt-hour meter will then measure the watt-hour loss in the field circuit of such motor; dividing by the time in hours will give the average loss in that field, and further dividing by the resistance of the field and extracting the square root of the result will give the square root of mean squared current in that motor, this being what is commonly known as the "heating current," which may be compared with the allowable figure for the motor under test (see p. 234). Observations of temperature of the various parts of the motor are usually made by a thermometer and checked by the drop of potential method. (Also see p. 234.)

Routine Tests. It is sometimes considered advisable either as a check on the operations of the motormen or as a check on the condition of the equipment to equip each motor car with some sort of a meter or timing device. Those most commonly in use are the current time clock, the coasting time recorder, ampere-hour meter and the watt-hour meter.

Current Time Clock. This device consists of a clock movement which operates only during the time when the current is being taken in the motor circuit. Readings are taken as each motorman goes on and off duty. Knowing the number of trips made by motorman and the total time consumed by them, the percentage of the total time during which current was on can be calculated and comparisons made between motormen.

Coasting Time Recorder. This instrument is similar to the current time clock except that it records the time during which the car is coasting. Its principle is based on the fact that the most economical run is the run with the most rapid rate of acceleration and with braking beginning at the lowest speed, thus making the coasting time the longest. In comparing motormen with this device the percentage of time during which the equipment was coasting is reckoned, the desired operation being that in which the coasting time is the longest.

Watt-hour Meter. Cars are equipped with a portable type of watt-hour meter connected to measure the energy consumption in the motor circuit. Readings are taken of the watt-hour meter as each motorman goes on and off duty and comparisons between motormen are made on the basis of kilowatt hours per car mile or per car hour, thus arriving directly at a comparison which is gotten at indirectly by the current time clock or coasting time recorder.

Ampere-hour Meter. As potential circuits of watt-hour meters are likely to give trouble, especially during thunder storms, the ampere-hour meter has been used as a check on energy consumption and gives the same or better results for comparative purposes as the watt hour meter, readings of ampere hours being reduced to ampere hours per car mile or per car hour for comparison.

Checks on Equipment as Well as on Motormen. The devices described above, designed primarily as a check on the operation of the controller and brake by motormen, have also been found of value by companies using them as a check as to the condition of the equipment and especially as an indication of too close brake adjustment. It has been stated that on some roads the saving in energy resulting from the use of one or another of such devices has amounted to from 10 to 25 per cent. of the total.

SECTION IV

RAILWAY MOTORS

Rating and Capacity of Railway Motors, A.I.E.E. Standardization Rules, 1914. The following numbered sections (415 to 449, inclusive) relative to the rating and capacity of railway motors are from the A.I.E.E. Standardization Rules, 1914:

415. Nominal Rating. The nominal rating of a railway motor shall be the mechanical output at the car or locomotive axle, measured in kilowatts, which causes a rise of temperature above the surrounding air, by thermometer, not exceeding 90 deg. C. at the commutator, and 75 deg. C. at any other normally accessible part, after one hour's continuous run at its rated voltage (and frequency in the case of an alternating-current motor) on a stand with the motor covers arranged to secure maximum ventilation without external blower. The rise in temperature, as measured by resistance, shall not exceed 100 deg. C.*

416. The statement of the nominal rating shall also include the corresponding voltage and armature speed.

417. Continuous Rating. The continuous ratings of a railway motor shall be the inputs in amperes at which it may be operated continuously at ½, ¾ and full voltage respectively, without exceeding the specified temperature rises (see **§420**), when operated on stand test with motor covers and cooling system, if any, arranged as in service. Inasmuch as the same motor may be operated under different conditions as regards ventilation, it will be necessary in each case to define the system of ventilation which is used. In case motors are cooled by external blowers, the volume of air on which the rating is based shall be given.

418. Maximum Input. The subject of overloads for railway motors is under investigation.

Temperature Limitations

419. The allowable temperature in any part of a motor will be governed by the kind of material with which that part is insulated. In view of space limitations, and the cost of carrying dead weight on cars, it is considered good practice to operate railway motors for short periods at higher temperatures than would be advisable in stationary motors. The following temperatures are permissible:

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* This definition differs from that in the 1911 edition of the Rules, principally by the substitution of a kilowatt rating for the horse-power rating and the omission of a reference to a room temperature of 25 deg. C. The horse-power rating of a railway motor may, for practical purposes, be taken as 4/3 of the kilowatt rating. On account of the hitherto prevailing practice of expressing mechanical output in horse-power, it is recommended that, for the present, the capacity be expressed both in kilowatts and in horse-power, a double rating, namely,

kw.————approx. equiv. h.p.————

In order to lay stress upon the preferred future basis, it is desirable that on rating plates, the rating in kilowatts shall be shown in larger and more prominent characters than the capacity in horse-power.

OPERATING TEMPERATURES*

Class of material†	Maximum observable temperature of windings when in continuous service			
	Short periods		Continuous	
	By thermometer	By resistance	By thermometer	By resistance
A2	100	125	85	110
B	115	145	100	130

*For infrequent occasions, due to extreme ambient temperatures, it is permissible to operate at 15 deg. higher temperature.

420. With a view to not exceeding the above temperature limitations the continuous ratings shall be based upon the **temperature rises** tabulated below:

TEMPERATURE RISES ON STAND TEST*

Class of material†	Temperature rises of windings	
	By thermometer	By resistance
A2	65	85
B	80	105

421. Field-control Motors. The nominal and continuous ratings of field-control motors shall relate to their performance with

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* The temperature rise in service may be very different from that on stand test. See **§440** for relation between stand test and service temperatures, as affected by ventilation.

† **188. Table of Hottest-spot Temperatures and of Corresponding Permissible Temperature Rises.**

Class	Description of insulation	Highest permissible temperatures for hottest spot	Highest permissible temperature rise of hottest spot above 40 deg. for the purpose of fixing the Institute rating
A1	Cotton, silk, paper and other fibrous materials, not so treated as to increase the thermal limit.	95 deg. C.	55 deg. C.
A2	Similar to A1, but treated or impregnated and including enameled wire.	105 deg. C.	65 deg. C.
B	Mica, asbestos or other material capable of resisting high temperatures, in which any Class A material or binder, if used, is for structural purposes only, and may be destroyed without impairing the insulating or mechanical qualities.	125 deg. C.	85 deg. C.
C	Fireproof and refractory materials	No limits specified	

the operating field which gives the maximum motor rating. Each section of the field windings shall be adequate to perform the service required of it, without exceeding the specified temperature rises.

Characteristic Curves

422. The characteristic curves of railway motors shall be plotted with the current as abscissas and the tractive effort, speed and efficiency as ordinates. In the case of alternating-current motors, the power factor values shall also be plotted as ordinates.

423. Characteristic curves of direct-current motors shall be based upon full voltage, which shall be taken as 600 volts, or a multiple thereof.

424. In the case of field-control motors, characteristic curves shall be given for all operating field connections.

Efficiency and Losses

425. The efficiency of railway motors shall be deduced from a determination of the losses enumerated in **§§426, 427, 428, 429** and **430.** (See also **§§436** and **437.**)

426. The copper loss shall be determined from resistance measurements corrected to 75 deg. C.

427. The no-load core loss, brush friction, armature bearing friction and windage shall be determined as a total under the following conditions:

In making the test, the motor shall be run without gears. The kind of brushes and the brush pressure shall be the same as in commercial service. With the field separately excited, such a voltage shall be applied to the armature terminals as will give the same speed for any given field current as is obtained with that field current when operating at normal voltage under load. The sum of the losses above mentioned is equal to the product of the counter-electromotive force and the armature current.

428. The **core loss** in d. c. motors shall be separated from the friction and windage losses above described by measuring the power required to drive the motor at any given speed without gears, by running it as a series motor on low voltage and deducting this loss from the sum of the no-load losses at corresponding speed. (See **§437** for alternative method.)

The friction and windage losses under load shall be assumed to be the same as without load, at the same speed.

The core loss under load shall be assumed as follows:

Per cent. of input at nominal rating	Loss as per cent. of no-load core loss
200	165
150	145
100	130
75	125
50	123
25 and under	122

NOTE: With motors designed for field control the core losses shall be assumed as the same for both full and permanent field. It shall be the mean between the no-load losses at full and permanent field increased by the percentages given in the above table.

429. The brush contact resistance loss to be used in determining the efficiency may be obtained by assuming that the sum of the drops at the contact surfaces of the positive and negative brushes is three volts.

430. The loss in gearing and axle bearings for single-reduction single-geared motors varies with type, mechanical finish, age and lubrication. The following values, based on accumulated tests, shall be used in the comparison of motors:

LOSSES IN AXLE BEARINGS AND SINGLE-REDUCTION GEARINGS

Per cent. of input at nominal rating	Losses as per cent. of input
200	3.5
150	3.0
125	2.7
100	2.5
75	2.5
60	2.7
50	3.2
40	4.4
30	6.7
25	8.5

436. In comparing projected motors and in case it is not possible or desirable to make tests to determine mechanical losses, the following values of these losses, determined from the averages of many tests over a wide range of sizes of single-reduction single-geared motors, will be found useful, as approximations. They include axle-bearing, gear losses, armature bearing, brush-friction, windage, and stray load losses.

Per cent. of input at nominal rating	Losses as per cent. of input
100 or over	5.0
75	5.0
60	5.3
50	6.5
40	8.8
30	13.3
25	17.0

437. The core loss of railway motors is sometimes determined by separately exciting the field and driving the armature of the motor to be tested by a separate motor having known losses and noting the differences in losses between driving the motor light at various speeds and driving it with various field excitations.

438. Selection of Motor For Specified Service.

The following information relative to the service to be performed is required in order that an appropriate motor may be selected.

(*a*) Weight of total number of cars in train (in tons of 2000 lb.) exclusive of electrical equipment and load
(*b*) Average weight of load and durations of same, and maximum weight of load and durations of same
(*c*) Number of motor cars or locomotives in train, and number of trail cars in train
(*d*) Diameter of driving wheels
(*e*) Weight on driving wheels, exclusive of electrical equipment

(*f*) Number of motors per motor car
(*g*) Voltage at train with power on the motors—average, maximum and minimum
(*h*) Rate of acceleration in m.p.h. per second
(*i*) Rate of braking (retardation in m.p.h. per second)
(*j*) Speed limitations, if any (including slowdowns)
(*k*) Distances between stations
(*l*) Duration of station stops
(*m*) Schedule speed including station stops in m.p.h.
(*n*) Train resistance in pounds per ton of 2000 lb. at stated speeds
(*o*) Moment of inertia of revolving parts, exclusive of electrical equipment
(*p*) Profile and alinement of track
(*q*) Distance coasted as a per cent. of the distance between station stops
(*r*) Time of lay over at end of run, if any.

439. Stand Test Method of Comparing Motor Capacity with Service Requirements. When it is not convenient to test motors under actual specific service conditions, recourse may be had to the following method of determining temperature rise.

440. The essential motor losses affecting temperatures in service are those in the motor windings, core and commutator. The mean service conditions may be expressed as a close approximation, in terms of that continuous current and core loss which will produce the same losses and distribution of losses as the average in service.

A stand test, with the current and voltage which will give losses equal to those in service, will determine whether the motor has sufficient capacity to meet the service requirements. In service, the temperature of an enclosed motor (§**97**),* well exposed to the draught of air incident to a moving car or locomotive, will be from 75 to 90 per cent. (depending upon the character of the service) of the temperature rise obtained on a stand test with the motor completely enclosed and with the same losses. With a ventilated motor (§§**98** and **100**),* the temperature rise in service will be 90 to 100 per cent. of the temperature rise obtained on a stand test with the same losses.

441. In making a stand test to determine the temperature rise in a specific service, it is essential in the case of a self-ventilated motor (§**100**),* to run the armature at a speed which corresponds to the schedule speed in service. In order to obtain this speed it may be necessary, while maintaining the same total armature losses, to change somewhat the ratio between the I^2R and core loss components.

***97. An "enclosed" machine** is so completely enclosed by integral or auxiliary covers as to prevent a circulation of air between the inside and outside of its case, but not sufficiently tight to be termed air-tight.

98. A "separately ventilated" machine has its ventilating air supplied by an independent fan or blower external to the machine.

100. A "self-ventilated" machine is a semi-enclosed machine, differing from a separately ventilated machine only in having its ventilating air circulated by a fan, blower, or centrifugal device integral with the machine.

If the heated air expelled from the machine is conveyed away through a pipe attached to the machine, this should be so stated.

442. Calculation for Comparing Motor Capacity with Service Requirements. The heating of a motor should be determined, wherever possible, by testing it in service, or with an equivalent duty cycle. When the service or equivalent duty cycle tests are not practicable, the ratings of the motor may be utilized as follows to determine its temperature rise.

443. The motor losses which affect the heating of the windings are as stated above, those in the windings and in the core. The former are proportional to the square of the current. The latter vary with the voltage and current, according to curves which can be supplied by the manufacturers. The procedure is therefore as follows:

444. (*a*) Plot a time-current curve and a time-voltage curve for the duty cycle which the motor is to perform, and calculate from these the root mean-square current and the equivalent voltage which with r.m.s. current will produce the average core loss.

445. (*b*) If the calculated r.m.s. service current exceeds the continuous rating, when run with average service core loss and speed, the motor is not sufficiently powerful for the duty cycle contemplated.

446. (*c*) If the calculated r.m.s. service current does not exceed the continuous rating, when run with average service core loss and speed, the motor is ordinarily suitable for the service. In some cases, however, it may not have sufficient thermal capacity to avoid excessive temperature rises during the periods of heavy load. In such cases a further calculation is required, the first step of which is to calculate the temperature rise due to the r.m.s. service current, and equivalent voltage.

$$\left.\begin{aligned} \text{Let } t &= \text{temperature rise} \\ p_0 &= I^2R \text{ loss, kw.} \\ p_c &= \text{core loss, kw.} \end{aligned}\right\} \text{with r.m.s. service current, and equivalent service voltage.}$$

$$\left.\begin{aligned} T &= \text{temperature rise} \\ P_0 &= I^2R \text{ loss, kw.} \\ P_c &= \text{core loss, kw.} \end{aligned}\right\} \text{with continuous load current corresponding to the equivalent service voltage.}$$

Then

$$t = T\frac{p_0 + p_c}{P_0 + P_c}, \text{ approximately.}$$

447. (*d*) The thermal capacity of a motor is approximately measured by a coefficient equal to the ratio of the electrical loss in kw. at its nominal (1-hour) capacity, to the corresponding maximum observable temperature rise.

448. (*e*) Consider any period of peak load and determine the electrical losses in kilowatt hours during that period from the *electrical* efficiency curve. Find the excess of the above losses over the losses with r.m.s. service current and equivalent voltage. The excess loss divided by the coefficient of thermal capacity will equal the extra temperature rise due to the peak load. This temperature rise added to that due to the r.m.s. service current, and equivalent voltage, gives the total temperature rise. If the total temperature rise in any such period exceeds the safe limit, the motor is not sufficiently powerful for the service.

449. (*f*) If the temperature reached due to the peak loads does not exceed the safe limit, the motor may yet be unsuitable for the service, as the peak loads may cause excessive sparking and dangerous mechanical stresses. It is, therefore, necessary to compare the peak loads with the short-period overload capacity. If the peaks are also within the capacity of the motor, it may be considered suitable for the given duty cycle.

Method of Approximating the Nominal Rating of a Motor Necessary for a Given Service. If the motor selected to move its portion of the weight of the train be of too great capacity it may operate at an efficiency disadvantage, moreover an added expenditure of energy will be caused in transporting its surplus weight, and due to this surplus weight, a part of which is generally not spring borne, there will result an increase in expense of truck and track maintenance. If, on the other hand, the motor selected be of too small capacity it may heat excessively, commutation may be defective, or possibly the torque will be insufficient to afford the required rate of acceleration or to maintain the desired schedule.

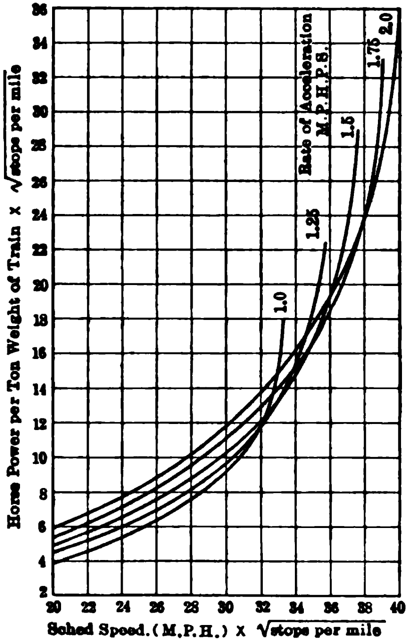

FIG. 1.—Curves for the preliminary determination of required horse-power rating of direct-current motor.

Curves for Preliminary Motor Rating Selection. Fig. 1 shows empirical curves from a paper by Mr. F. W. Carter, Institution of Electrical Engineers, 1906. These curves may be used for the *preliminary selection* of a motor of proper rating. In obtaining these curves, the characteristics of a normal railway motor were taken, and from them was deduced a set of train characteristics, corresponding to different rates of acceleration and different ranges of speed-curve running, care being taken that the motor was always employed as it actually would be in normal suburban service. To allow for the inertia of rotating parts the effective weight of the train was taken as 8 per cent. in excess of the actual weight. Coasting was assumed to occupy 17½ per cent.

of the total running time. The average rate of braking was taken at 1.75 miles per hour per second. For train resistance, constant figures of 13 lb. per ton while power is on and 15 lb. per ton during coasting were assumed, it being impracticable to allow these figures to vary with the speed. The rated motor horse-power required for the train will then be approximately equal to the value "Horse-power per ton weight of train, $\times\sqrt{\text{stops per mile}}$" (obtained from the curve) divided by $\sqrt{\text{stops per mile}}$ and multiplied by the number of tons weight of train.

In the following is outlined a method of selecting a motor to be first considered in deciding on a motor for a given service. The motor thus selected may not be the one best suited for the particular service, but its use in plotting preliminary run curves will give a start toward making a more accurate selection of a motor to be finally investigated for capacity as limited by heating. Briefly the method is as follows: First, approximate both the value of power required to propel the train and the current flowing at the end of the straight line acceleration period on a typical run of the service to be supplied by the motor. Then select the motor whose nominal rating (see A.I.E.E. Standardization Rules, page 221) is nearest these approximate values of power required and current flowing. These values are given by the following formulas:

$$P = \frac{WTS \times 1.467 \times 745.6}{n \times 550 \times 1000}$$

$$= \frac{WTS}{500\,n} = \frac{0.002\,WTS}{n}$$

$$P_1 = \frac{WTS}{375\,n} = \frac{0.00267\,WTS}{n}$$

$$I = \frac{2\,WTS}{UE} \text{ for direct current}$$

$$= \frac{2\,WTS}{UjE} \text{ for single phase}$$

in which

P = nominal rating of motor according to A.I.E.E. Standardization Rules, 1914, kilowatts

NOTE: The approximations $\frac{WTS}{500\,n}$ and $\frac{0.002\,WTS}{n}$ are convenient and sufficiently accurate for most practical work. The true values are $\frac{WTS}{503\,n}$ and $\frac{0.00199\,WTS}{n}$, respectively

P_1 = nominal rating of motor according to A.I.E.E. Standardization Rules, 1914, horse-power

I = nominal current per motor at output P, amperes

n = number of similar motors driving train

W = total weight of train (including load and motors), tons

T = approximate total tractive effort required at the driving wheel treads of the train during straight line acceleration, at the end of straight line acceleration period, pounds per ton

$$= \left(\frac{A}{0.01098K} + f + C \pm G\right) \text{ for grades and curves}$$

$$= \left(\frac{A}{0.01098K} + f\right) \text{ on tangent level track}$$

in which A = rate of straight line acceleration, miles per hour per second

K = approximate ratio of linear inertia to total inertia of train (see page 172). Unless more definitely known, the value of K may be taken to be 0.90 for a trial

C = track curve resistance (see p. 169), pounds per ton weight of train

G = track grade resistance (see p. 170), pounds per ton weight of train

f = approximate train resistance (see p. 147) at the end of straight line acceleration (at speed S, which see below), pounds per ton weight of train. Unless more definitely known, the value of f may, for trial, be taken to be 15 lb. per ton weight of train

S = speed of train at end of straight line acceleration period of typical run on section over which motor is to operate, miles per hour. If the value of S is not known it may, for trial, be taken to be 60 per cent. of the maximum speed attained during the typical run. If the maximum speed attained during the typical run is not known, the value of S may be approximated by the following process: Let L = the length of the typical run, miles; and let t' = time the train is in motion, seconds from start to stop. From Fig. 60 (p. 193) find the maximum speed S' attained by making a 1-mile run in $\frac{t'}{\sqrt{L}}$ seconds with a gross tractive effort T (whose value is given above). Then the required approximate speed of train, at the end of the straight line acceleration period, $S = S' m \sqrt{L}$ in which m = ratio of speed of train at end of straight line acceleration period of typical run to maximum speed attained by the train during the typical run. The value of m is fixed by experience, but for a trial it may be taken to be 0.6

U = approximate full load efficiency of motor decimally expressed. Its value may be taken as that of the motor which it is suspected may be used, or, for trial, it may be taken to be 0.85

E = electromotive force applied to motors at end of straight line acceleration period of typical run, volts.

(It is assumed that all motors will be subjected to the same electromotive force at the end of the straight line acceleration period.) If, in direct-current operation, the motors are all in parallel and have no resistance in series with them, this is the trolley or third rail potential at the car

j = power factor of motor at nominal rated load. It may be that for the motor which it is suspected may be used, or, for trial, its value may be taken to be 0.90.

The available motor having a nominal rating (see A.I.E.E., Standardization Rules, p. 221) nearest the above value of P at the above current I and the electromotive force E may then be selected as the first motor to be tried in furthering the investigation. The next step is to construct the speed-time curve for the train and the current per motor time curve (see Run Curves, p. 177) with the motor selected for trial. If the nominal rated full load current gives a value of tractive effort greater than is necessary for the required rate of straight line acceleration a smaller motor or a lower gear ratio should be tried. If, on the other hand, the nominal rated full load current gives a value of tractive effort less than is necessary for the required rate of straight line acceleration, a larger motor or a higher gear ratio should be tried. Whether the motor or gear ratio or both should be changed is a matter to be decided on the proportion of the required tractive effort that the full load tractive effort is in excess or lacking, and the rating of the motors available. Except for capacity as limited by heating, the suitability of the motor and gear ratio selected will be indicated on the plotting of the entire speed-time curve. The highest gear ratio (lowest speed gear) with which the run can be made in the required time will generally bring about the coolest motor operation and the least energy consumption per car mile. It is common practice, however, to make the selection so that, in order to compensate for incidental delays, the train can make the run in about 10 per cent. less than the schedule time. Ordinary rush hour loads will thus be provided for. The heavier rush hour loads or trailer service during a portion of the time of operation must be provided for by selecting a larger motor than is necessary for the ordinary service, or by depending upon a possible overload capacity of the motor if this overload endures only for a period permissible by the heating capacity of the motor.

The capacity of a motor which is sufficiently strong mechanically and will commutate satisfactorily is limited by the heating of the motor by the energy dissipated as losses. Therefore, a study of the motor and gear ratio must be made with regard to motor heating by making a comparison with the service requirements.

Details of Indirect Methods of Comparison of Motor Capacity with Service Requirements

Method by Continuous Capacity of Motor. The method outlined in the following, of investigating to determine whether or not the capacity of a given motor equipment is sufficient for a given service is due to Mr. N. W. Storer, Street Railway Journal, 1901, and Electric Journal, 1908. The method consists in running the motor on a testing stand at such values of current and voltage that the windings losses and core losses resulting will be equal to the average windings losses and core losses of the motor in actual service. (See Par. 420, p. 222.) The motor temperatures reached during the test are noted. These values of current and voltage are called "equivalent heating current" and "equivalent voltage," respectively and may be obtained as indicated in the following:

Equivalent Heating Current. This is the value of the current which during the total time of the run (including accelerating, coasting, braking and stop periods) would cause a total energy loss in the windings equal to that for the run. (Also see under Equivalent Voltage, p. 232.) It is equal to the square root of the average square of the current throughout the run. If the abscissa of each of several points of the curve of amperes per motor plotted with time as abscissas (see Fig. 2) be squared and the values of these squares be plotted and the successive points thus found, connected, a curve of $(\text{current})^2$ values will result. The "equivalent heating current" will then be equal to $\sqrt{\frac{Ait}{T}}$ in which

A = area under $(\text{current})^2$ curve, square units
t = the number of seconds represented by each unit abscissa
i = the number of amperes represented by each unit ordinate
(NOTE: units used in A, t and i are the same.)
T = total time of run (sum of accelerating, coasting. braking and stop periods) seconds.

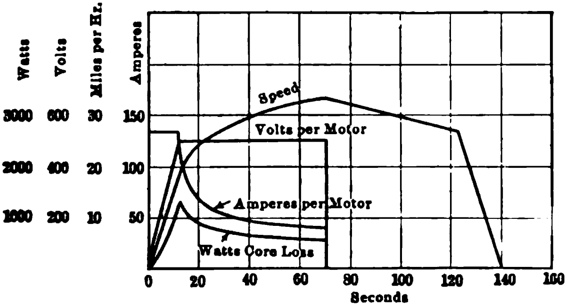

FIG. 2.—Typical curves of speed, current, voltage and core loss.

Core Loss Curve. The loss represented by the abscissa of any point on the core loss curve is equal to the core loss in the motor due to the voltage applied to and the current flowing in the motor at that instant. These values of voltage, current and core loss may be obtained from the volts per motor and current per motor curves, respectively, for the equipment and run (see Fig. 2) and the core loss curves (plotted in terms of power and voltage) for the motor (Fig. 3 is typical). As an example of the method of plotting a point on the core loss curve, suppose it is desired to find the point of the core loss curve at 20 seconds from the start of the run. From the current per motor and the volts per motor curves (Fig. 2) it is found that at 20 seconds from the start of the run there are 69 amperes and 500 volts per motor. Entering Fig. 3 at the 500-volt point, the core loss corresponding to 69 amperes is found to be 900 watts; 900 watts plotted at the 20-second point will be the desired point of the core loss curve.

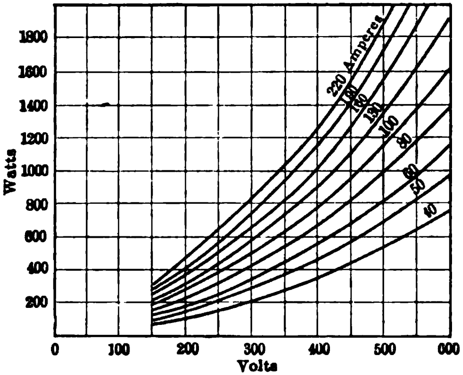

Fig. 3.—Typical core loss curves.

Average Core Loss. The value of the average core loss is

$$\frac{A_1 tp}{T}$$

in which A_1 = area under core loss curve, square units
t = number of seconds represented by each unit abscissa
p = the number of watts represented by each unit ordinate
(NOTE: units used in A_1, t and p are the same.)
T = total time of run (sum of accelerating, coasting, braking and stop periods), seconds.

Equivalent Voltage. The equivalent voltage is that voltage which with the equivalent heating current (see p. 231) gives the average core loss (see above). Its value may be obtained from the core loss curves for the particular motor (see Fig. 3). Relative to 500-volt motors, Mr. N. W. Storer has stated that calculations and tests show that an equivalent voltage of 300 will cover average conditions in city service and that where there are few stops such as in interurban service, an equivalent voltage of 400 will suffice.

Discussion of Continuous Capacity Method. The internal ventilation in service and on the testing stand is practically the same, therefore the internal interchange of heat is practically the same in both cases. Due to difference in ventilation affecting external radiation the motor will run cooler in service than on the testing stand. The extent to which this is so depends upon air temperature, its velocity and circulation over the radiating surfaces, the schedule speed of the train and the length of stop during which (in still air) the heat is radiated as in the stand test. (See Par. 420, p. 222 and Par. 440, p. 225.)

Comparison of Motor Capacity by Losses. It has been proposed to compare motor capacities by comparing the energy losses per unit weight of motor. This method is of little value and it may, in some cases, be misleading because the heating of a motor depends upon the dissipation of the energy of loss rather than the magnitude of the losses. Thus, of two motors having the same weight, rating and efficiency, the better ventilated will run the cooler.

Load-time Curve. (See Fig. 4 for specimen curves.) A load-time curve for a given motor indicates the time during which a certain value of current flowing in the motor in air of a certain temperature will raise the temperature of the motor a certain amount from some other value of temperature. Two temperature ranges are most commonly taken for load-time curves, namely, (*a*) 75 deg. C. rise from a temperature of 25 deg. C. and (*b*) 20 deg. C. rise from a temperature of 75 deg. C. (the temperature of the surrounding air being 25 deg. C. in both cases). The former (75 deg. C. rise from a temperature of 25 deg. C.) at its 60-minute point indicates the nominal rating of the motor. This curve also shows the length of time the motor may safely carry any current at the rated voltage. It also shows the shortest time during which the equivalent heating current (see p. 231) may be

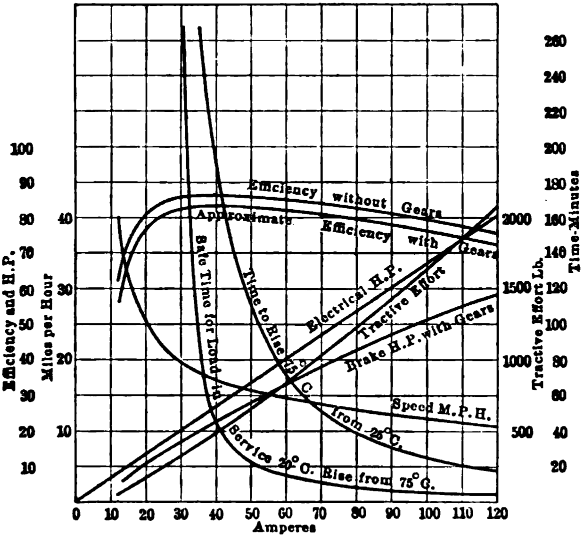

FIG. 4.—Railway motor characteristic curves showing load-time curves. (35 h.p., 500 volts, pinion 18, gear 66, ratio 3.66, wheels 33 in.)

allowed to reach any value at the rated voltage. The latter curve (20 deg. C. rise from a temperature of 75 deg. C.) by its vertical portion indicates the value of current the motor may carry constantly with its temperature at 75 deg. C. This curve also shows the length of time during which any current will raise the temperature of the motor to a value of 20 deg. C. above 75 deg. C.

Measurements in Service Tests.

Current.—The current taken by a motor in a service test may be most conveniently determined by means of a recording ammeter in the motor circuit. An indicating ammeter may be used by taking periodic readings and recording the time of each reading. If only the equivalent heating current (see above) is desired for direct-current operation it may be obtained conveniently by the following method: A specially calibrated watt-hour meter is connected to record the energy lost in the motor field winding, as shown by Fig. 5, then the equivalent heating current will be equal to $\sqrt{\frac{e}{RT}}$

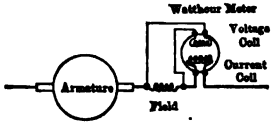

FIG. 5.—Watt-hour meter connected to measure I^2R loss.

in which e = energy lost on motor field, watt hours
R = operating resistance of motor field, ohms
T = total time during which the equivalent current is desired (sum of accelerating, coasting, braking and stop periods), hours.

Voltage.—The voltage may be most conveniently determined by means of a recording voltmeter connected across the motor terminals. An indicating voltmeter may be used by taking periodic readings and recording the time of each reading.

Temperature.—Mr. Clarence Renshaw, A.I.E.E., 1903, gives the following method used by him in successfully measuring the temperature in a field coil during a service test: A small temperature coil consisting of 48 ft. of No. 27 annealed iron wire was calibrated in an oil bath, and an accurate comparison between its resistance and the temperature was obtained. This wire was then wound on two thin wooden strips, and during the process of winding a field coil for use on one of the motors these two strips were placed in the interior of the coil, one on each side, about half way between the center and the outside. The resistance of this wire was determined by means of a portable wheatstone bridge, at 5-minute intervals during the test. From these resistances and the resistance-temperature relation the temperature of the interior of the field coil was determined. During the test on which this method was used unsatisfactory results were obtained in trying to get the armature temperature by means of resistance tests during lay-overs. In this connection, Mr. Renshaw states, "As far as could be judged. . .the temperature of the armature was not materially different from that of the field."

Standard General Electric Railway Motors

NON-COMMUTATING POLE TYPE, DIRECT CURRENT 500 VOLTS

Motor		No. motors	Type control	Weight of motor including gear and gear case, pounds	Weight, total equipment, pounds
Name	H.p.				
54[1]	25	2	K–10	1,900	4,760
		4	K–12		8,865
60[1]	25	2	K–10	1,700	4,360
		4	K–12		8,065
800	25	2	K–10	1,950	4,860
		4	K–12		9,065
81	30	2	K–10	2,020	5,000
		4	K–12		9,345
78	35	2	K–10	2,580	6,080
		4	K–28		11,630
1000[1]	35	2	K–10	2,185	5,330
		4	K–28		10,200
*58[1]	37	2	K–10	2,225	5,410
		4	K–28		10,360
67[1]	40	2	K–10	2,450	5,860
		4	K–28		11,260
*80	40	2	K–10	2,850	6,660
		4	K–28		12,860
88	40	2	K–10	3,070	7,080
		4	K–28		13,630
70[1]	40	2	K–10	2,750	6,460
		4	K–28		12,460
53[1]	45	2	K–11	2,850	6,750
		4	K–14		13,665
57[1]	50	2	K–11	3,030	7,110
		4	K–14		14,385
		4	Mult. unit		14,745
90[1]	50	2	K–36	2,875	6,765
		4	K–35		13,750
		4	Mult. unit		14,171
*98	50	2	K–36	3,290	7,815
		4	K–35		14,910
		4	Mult. unit		15,865
*87	60	2	K–28	3,380	7,783
		4	K–34		15,796
		2	Mult. unit		8,690
		4	Mult. unit		16,207
74[1]	65	2	K–28	3,535	8,530
		4	K–34		15,600
		2	Mult. unit		9,360
		4	Mult. unit		16,295

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[1] These motors have been superseded by later types, but owing to their widespread use, data concerning them are included for comparison.

* Characteristic curves, Figs. 6 to 9.

GE 500-Volt Non-commutating Pole Motors.—*Continued*

Motor		No. motors	Type control	Weight of motor including gear and gear case, pounds	Weight total equipment, pounds
Name	H.p.				
*73	75	2	K–28	4,137	9,740
		4	K–34		18,760
		2	Mult. unit		10,580
		4	Mult. unit		19,670
*66	125	2	Mult. unit	4,400	11,515
		4	Mult. unit		21,270
55	160	2	Mult. unit	5,420	14,085
		4	Mult. unit		27,520
76	160	2	Mult. unit	5,170	13,585
		4	Mult. unit		26,520
69†	200	2	Mult. unit	6,250	15,820
		4	Mult. unit		31,000

GE 600-Volt D.C. Commutating Pole Type Railway Motors

Motor		No. motors	Type control	Weight of motor including gear and gear case, pounds	Weight total equipment, pounds
Name	H.p.				
200	40	2	K–36	2,120	5,490
		4	K–35		9,880
		4	Mult. unit		10,410
226	45	2	K–36	2,180	5,620
		4	K–35		10,430
		4	Mult. unit		10,670
203	50	2	K–36	2,150	5,550
		4	K–35		10,270
		4	Mult. unit		10,550
*203	50	2	K–36	2,600	6,450
		4	K–35		12,100
		4	Mult. unit		12,350
216	50	2	K–36	2,875	7,000
		4	K–35		13,200
		4	Mult. unit		13,450
219	50	2	K–36	2,887	6,833
		4	K–35		13,140
		4	Mult. unit		13,390
201	65	2	K–36	2,735	6,710
		4	K–35		12,610
		2	Mult. unit		7,490
		4	Mult. unit		13,100
201	65	2	K–36	2,870	7,000
		4	K–35		13,180
		2	Mult. unit		7,690
		4	Mult. unit		13,280

* Characteristic curves, Fig. 10, 11, and 12.

† This motor has been superseded by later types, but owing to its widespread use, data concerning it is included for comparison.

GE 600-VOLT D.C. COMMUTATING POLE TYPE RAILWAY MOTORS.—*Continued*

Motor		No. motor	Type control	Weight of motor including gear and gear case, pounds	Weight, total equipment, pounds
Name	H.p.				
*210	70	2	K-36	3,380	7,750
		4	K-34		15,710
		2	Mult. unit		8,690
		4	Mult. unit		15,680
218	70	2	K-36	3,200	8,100
		4	K-34		15,000
		2	Mult. unit		8,330
		4	Mult. unit		14,960
204	75	2	K-35	3,400	8,500
		4	K-34		15,800
		2	Mult. unit		8,730
		4	Mult. unit		15,760
*214	80	2	K-35	3,806	9,282
		4	K-34		17,414
		2	Mult. unit		9,430
		4	Mult. unit		17,240
*205	110	2	K-35	3,925	9,200
		4	K-44		18,330
		2	Mult. unit		9,800
		4	Mult. unit		18,300
225	115	2	Mult. unit	3,860	10,200
		4	Mult. unit		18,760
222	140	2	Mult. unit	4,100	10,710
		4	Mult. unit		19,900
207	165	2	Mult. unit	5,160	13,050
		4	Mult. unit		25,950
212	235	2	Mult. unit	6,000	14,800
		4	Mult. unit		29,780
209	275	4	Mult. unit	10,400	50,930
GE 600/1200-VOLT D.C. COMMUTATING POLE TYPE RAILWAY MOTORS					
217	50	2	K-42	3,250	8,650
		4	K-47		15,150
		4	Mult. unit		17,150
*205-A	80	2	K-42	3,850	9,850
		4	K-47		17,600
		4	Mult. unit		19,730
225	105	4	Mult. unit	3,860	20,980
205	110	2	Mult. unit	3,930	10,400
		4	Mult. unit		18,250
207	110	4	Mult. unit	5,160	26,220
222	130	4	Mult. unit	4,100	22,380
*207-A	140	4	Mult. unit	5,160	26,870
GE 1200-VOLT D.C. COMMUTATING POLE TYPE RAILWAY MOTORS					
205	80	2	K-42	3,850	9,850
			Mult. unit		20,000

*Characteristic curves, Figs. 13 to 17.

Standard Westinghouse Railway Motors

DIRECT-CURRENT NON-COMMUTATING POLE TYPE

(Designed prior to 1904)

Motor		No. motors	Type control	Weight of motor including gear and gear case, pounds	Weight, total equipment, pounds
Name	H.p.				
*12–A	25	2	K–10	2,200	5,400
		4	K–12		10,140
12–A	30	2	K–10	....	5,400
		4	K–12		10,140
*69	30	2	K–10	1,950	4,900
		4	K–12		9,140
*49	35	2	K–10	1,925	4,900
		4	K–28		9,300
92–A	35	2	K–10	2,265	5,580
		4	K–28		10,500
68–C	40	2	K–10	2,280	5,600
		4	K–28		10,560
101	40	2	K–10	2,645	6,340
		4	K–28		12,020
101–C	40	2	K–10	2,780	6,700
		4	K–28		12,700
38–B	50	2	K–10	2,380	5,810
		4	K–28		10,960
*93–A	60	2	K–11	3,440	8,080
		4	K–14		16,360
56	60	2	K–11	3,000	7,200
		4	K–14		14,400
112	75	2	Unit switch	3,440	8,775
		4	Unit switch		15,820
76	75	2	Unit switch	3,840	9,575
		4	Unit switch		17,420
85	75	2	Unit switch	4,500	10,895
		4	Unit switch		20,060
121	90	2	Unit switch	4,300	10,530
		4	Unit switch		20,015
*119	125	2	Unit switch	4,680	11,425
		4	Unit switch		21,610
*113	195	2	Unit switch	6,550	15,795
		4	Unit switch		Special
*101–B–2	40	2	K–10–A	2,780	6,635
		4	K–28–B		12,620
		2	Unit switch		7,225
		4	Unit switch		13,065
101–D–2	50	2	K–36–J	2,780	6,705
		4	K–35–G		12,695
		2	Unit switch		7,245
		4	Unit switch		13,100

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* Characteristic curves, Figs. 18 to 24.

Westinghouse D.C. Non-commutating Pole Type Railway Motors.—*Continued*

(Designed since 1904)

Motor		No. motors	Type control	Weight of motor including gear and gear case, pounds	Weight, total equipment, pounds
Name	H.p.				
93-A-2	60	2	K-36-J	3,440	8,100
		4	K-34-D		15,900
		2	Unit switch		8,585
		4	Unit switch		15,815
*112-B	75	2	K-35-G	3,485	8,505
		4	K-34-D		16,245
		2	Unit switch		8,860
		4	Unit switch		16,000
121-A	90	2	K-35-G	4,300	10,130
		4	K-34-D		19,500
		2	Unit switch		10,530
		4	Unit switch		19,815
*114	160	2	Unit switch	5,300	13,080
		4	Unit switch		Special

Westinghouse D.C. Commutating Pole Railway Motors

Motor			No. motors	Type control	Weight of motor including gear and gear case, pounds	Weight, total equipment, pounds
Name	H.p.					
	600 V.	500 V.				
328	37	30	2	K-11-M	1,680	4,400
			4	K-28-U		8,155
			2	Unit switch		4,480
			4	Unit switch		8,365
323-A	40	33	2	K-11-M	1,890	4,820
			4	K-28-U		8,995
			2	Unit switch		5,445
			4	Unit switch		9,505
312	50	40	2	K-11-M	2,630	6,300
			4	K-28-U		11,955
			2	Unit switch		6,945
			4	Unit switch		12,505
307	50	40	2	K-36-J	2,850	6,815
			4	K-35-G		12,995
			2	Unit switch		7,385
			4	Unit switch		13,390
†319-B	50	40	2	K-36-J	2,865	6,845
			4	K-35-G		13,055
			2	Unit switch		7,415
			4	Unit switch		13,450
306	60	50	2	K-36-J	2,850	6,815
			4	K-35-G		12,995
			2	Unit switch		7,400
			4	Unit switch		13,455
†316	60	50	2	K-36-J	3,050	7,215
			4	K-35-G		14,190
			2	Unit switch		7,800
			4	Unit switch		14,255

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* Characteristic curves, Figs. 25 and 26.

† Characteristic curves, Figs. 27 and 28.

WESTINGHOUSE D.C. COMMUTATING POLE RAILWAY MOTORS.—*Continued*

Motor			No. motors	Type control	Weight of motor including gear and gear case, pounds	Weight, total equipment, pounds
Name	H.p.					
	600 V.	500 V.				
305	75	60	2	K-36-J	3,550	8,215
			4	K-34-D		16,370
			2	Unit switch		9,000
			4	Unit switch		16,360
310	75	60	2	K-36-J	3,440	7,995
			4	K-34-D		15,930
			2	Unit switch		8,780
			4	Unit switch		15,920
304	90	75	2	K-35-G	3,550	8,655
			4	K-34-D		16,525
			2	Unit switch		9,000
			4	Unit switch		16,360
*317	90	75	2	K-35-G	3,660	8,875
			4	K-34-D		16,965
			2	Unit switch		9,220
			4	Unit switch		16,800
303-A	110	......	2	Unit switch	4,150	10,230
			4	Unit switch		19,220
*302-A	140	......	2	Unit switch	4,685	11,430
			4	Unit switch		21,630
*301-B	175	......	2	Unit switch	5,510	13,500
			4	Unit switch		Special
300-B	220	......	2	Unit switch	6,400	15,500
			4	Unit switch		Special

WESTINGHOUSE 1200- AND 1500-VOLT D.C. RAILWAY MOTORS

Motor			No. motors	Type control	Weight of motor including gear and gear case, pounds	Weight, total equipment, pounds
Name	H.p.					
	600 V.	500 V.				
*333	115	100	2	Unit switch	3,900	Special
			4	Unit switch		Special
	750 V.	600 V.				
*321	110	90	2	Unit switch	4,150	Special
	110	90	4	Unit switch		Special
*322	140	115	2	Unit switch	4,685	Special
	140	115	4	Unit switch		Special
*308-D-3	260	225	2	Unit switch	6,740	Special
	260	225	4	Unit switch		Special

* Characteristic curves, Figs. 29 to 35.

WESTINGHOUSE SINGLE-PHASE A.C. RAILWAY MOTORS

For Motor Cars

Motor		No. motors	Type control	Weight of motor including gear and gear case, pounds	Weight, total equipment, pounds
Name	H.p.				
•135	75	4	Unit switch	4,500	Special
132	100	4	Unit switch	5,100	Special
132–A	100	4	Unit switch	5,575	Special
•132–C	100	4	Unit switch	5,575	Special
132–F	100	4	Unit switch	5,700	Special
•148–A	125	4	Unit switch	6,100	Special
•133	135	4	Unit switch	6,000	Special
•156	150	4	Unit switch	7,700	Special
409	175	4	Unit switch	7,846[1]	Special
409–B	175	2	Unit switch	6,700	Special
409–D	175	4	Unit switch	7,846[1]	Special
For Locomotives					
410	125	4	Unit switch	13,365[1]	Special
•409–C[2]	175	4 pairs	Unit switch	16,500[1]	Special
151	175	4	Unit switch	10,600	Special
137	240	3	Unit switch	15,700	Special
•130	250	4	Unit switch	16,400	Special
403	310	4	Unit switch	21,220[1]	Special
•403–A	310	4	Unit switch	19,800[1]	Special
403–B	310	4	Unit switch	19,800[1]	Special
406	675	2	Unit switch	41,200	Special

[1] Motors arranged for quill drive. Weights here include drive details.

[2] 409–C motor is arranged to operate in pairs. Weight given is for one pair of motors complete with drive details.

ALLIS CHALMERS DIRECT-CURRENT RAILWAY MOTORS

Motor		No. motors	Type control	Weight of motor including gear and gear case, pounds	Weight, total equipment, pounds
Name	H.p.				
•301	40	2	S–3	2,630	6,550
		4	S–4		12,300
•501	50	2	S–3	2,610	6,450
		4	S–4		12,100
•302	55	2	S–3	3,060	7,640
		4	S–4		14,030

• Characteristic curves, Figs. 36 to 46.

Motors for Low Floor Cars. Motors commonly known as "Low Floor," "Dachshund" and "Baby," for use on low floor cars built with small wheels, are of smaller diameter than but do not differ in general electrical design from motors ordinarily used with 33-in. wheels.

Pressed Steel Motor. Certain railway motor parts formerly made of cast steel are now made of pressed steel, for some of the motor capacities of most common application. The weight of a 40-h.p. pressed steel motor is about 12 per cent. less than a cast steel motor of the same capacity.

Railway Motor Characteristic Curves. Figs. 6 to 46, inclusive, give the operating characteristics of some of the commercial motors when operating at particular voltages with particular gear ratios and driving-wheel diameters. The ordinates for the *tractive effort* curve for a series motor with any gear ratio or driving-wheel diameter may be derived from the ordinates of the original *tractive effort* curve for that motor as follows:

$$T^1 = T\left(\frac{G^1 \times D}{G \times D^1}\right)$$

in which T^1 = tractive effort ordinate for any current value on the derived curve

T = tractive effort ordinate for the same current value on the original curve

G^1 = gear ratio for derived tractive effort curve

G = gear ratio for original tractive effort curve

D^1 = driving-wheel diameter for derived tractive effort curve

D = driving-wheel diameter for original tractive effort curve.

The approximate values of the ordinates of the *speed* curve for a series motor with any gear ratio or driving-wheel diameter operating at any other electromotive force, differing slightly from the electromotive force at which the original speed curve was obtained, may be derived from the original *speed* curve as follows:

$$S^1 = S\left(\frac{E^1 \times G \times D^1}{E \times G^1 \times D}\right)$$

in which S^1 = speed ordinate for any current value on the derived curve

S = speed ordinate for the same current value on the original curve

E^1 = e.m.f. for derived speed curve

E = e.m.f. for original speed curve.

(NOTE: When the electromotive force is not changed, that is, when $E^1 = E$, the value given for S^1 is exact.)

Example of the Derivation of Tractive Effort and Speed Curves. Fig. 48 (p. 265) shows tractive effort and speed curves (dotted) derived from the original curves by the above process as follows: The original gear ratio, wheel diameter and voltage are 2.78, 33, and 500, respectively, and it is desired to derive the tractive effort and approximate speed curves for a gear ratio, wheel diameter and voltage of 3.83, 36, and 550, respectively. In this case, $G^1 = 3.83$, $G = 2.78$, $D^1 = 36$, $D = 33$, $E^1 = 550$ and $E = 500$. Therefore

$$T^1 = T\left(\frac{3.83 \times 33}{2.78 \times 36}\right)$$
$$= 1.26\,T$$

and

$$S^1 = S\left(\frac{550 \times 2.78 \times 36}{500 \times 3.83 \times 33}\right)$$
$$= 0.87\,S$$

Thus in Fig. 48 the dotted tractive effort curve is the locus of all points the ordinate of each of which is equal to 1.26 times the corresponding ordinate on the original tractive effort curve, and the dotted speed curve is the locus of all points the ordinate of each of which is equal to 0.87 times the corresponding ordinate on the original speed curve.

(NOTE: Where, as for preliminary investigation, only one or very few points on the derived characteristic may be desired, it may be advantageous to obtain the desired derived values by the above method of calculation directly without actually plotting the derived curve.)

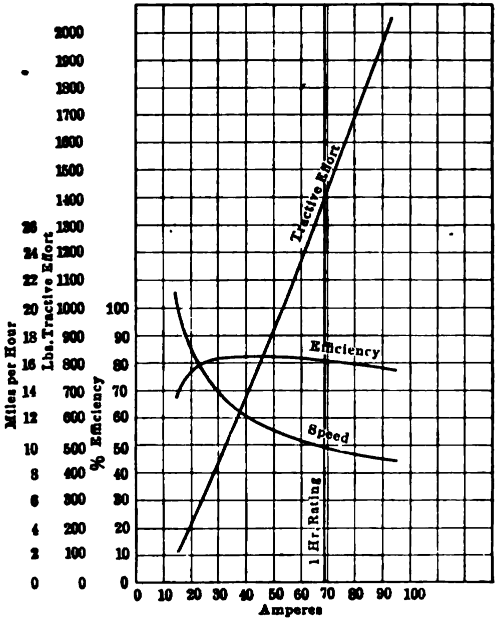


FIG. 6.—General Electric No. 58 railway motor. 37 h.p., 500 volts, pinion 15, gear 69, ratio 4.60, wheels 30 in.

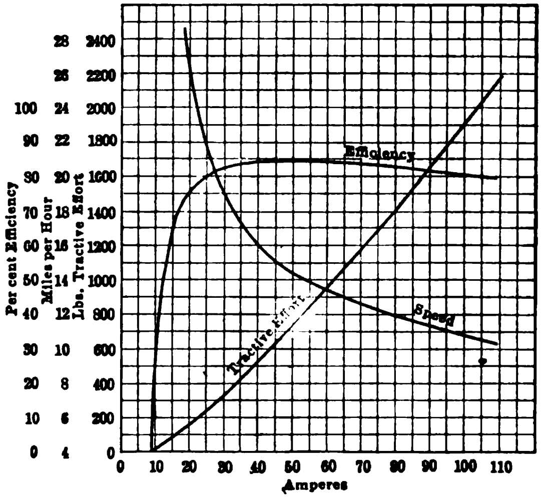


FIG. 7.—General Electric No. 80 railway motor. 40 h.p., 500 volts, pinion 17, gear 69, ratio 4.06, wheels 33 in.

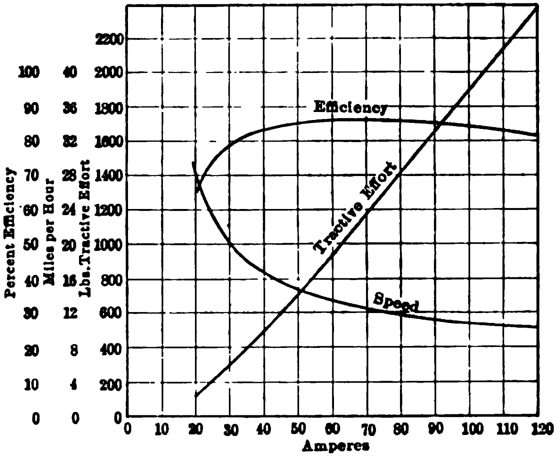


FIG. 8.—General Electric No. 98 railway motor. 50 h.p., 500 volts, pinion 16, gear 71, ratio 4.43, wheels 33 in.

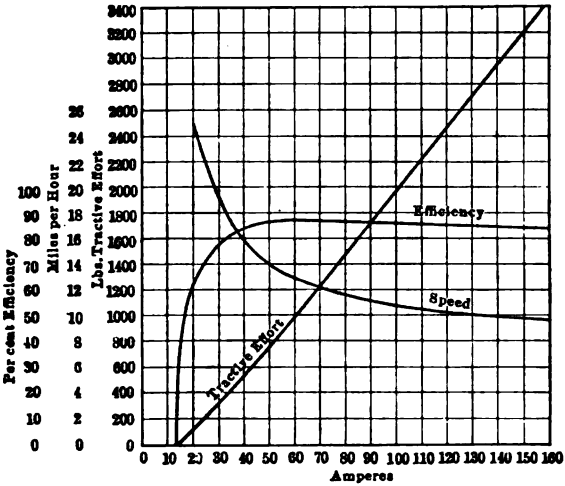


FIG. 9.—General Electric No. 87 railway motor. 60 h.p., 500 volts, pinion 16, gear 71, ratio 4.44, wheels 33 in.

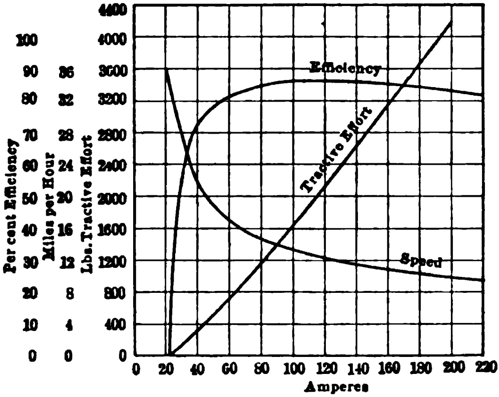


FIG. 10.—General Electric No. 73 railway motor. 75 h.p., 500 volts, pinion 17, gear 73, ratio 4.30, wheels 33 in.

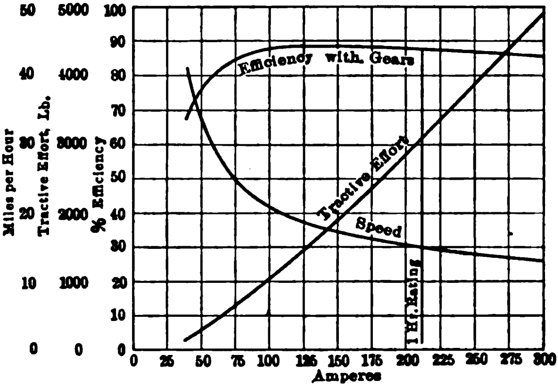


FIG. 11.—General Electric No. 66 railway motor. 125 h.p., 500 volts, pinion 17, gear 61, ratio 3.59, wheels 33 in.

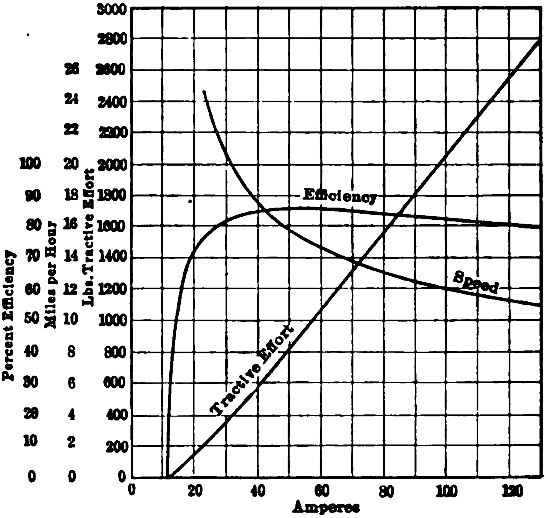


FIG. 12.—General Electric No. 203 railway motor. 50 h.p., 600 volts, pinion 15, gear 69, ratio 4.60 wheels 33 in.

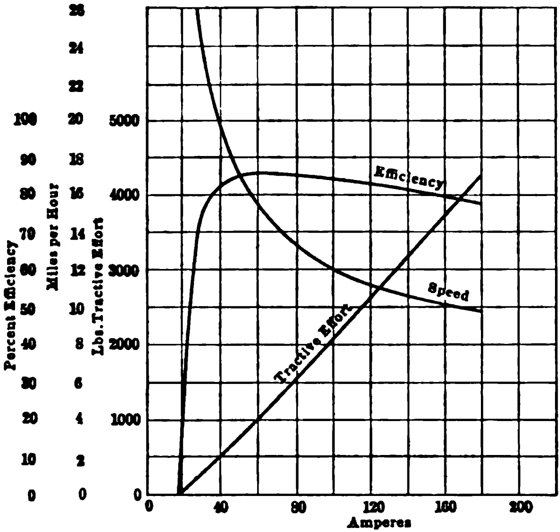


FIG. 13.—General Electric No. 210 railway motor. 70 h.p., 600 volts, pinion 16, gear 71, ratio 4.43, wheels 33 in.

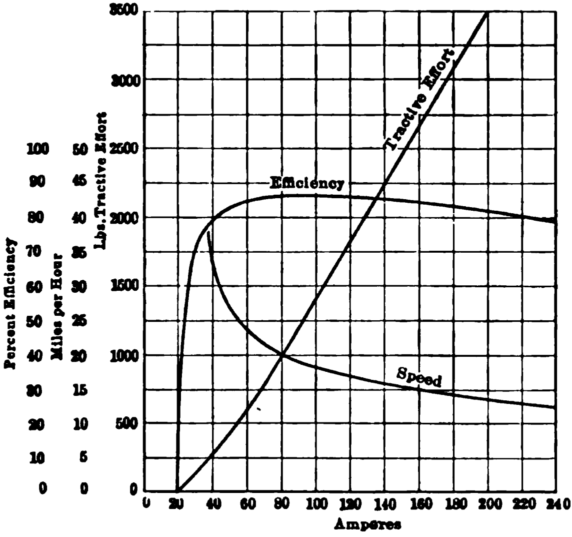


FIG. 14.—General Electric No. 214 railway motor. 75 h.p., 600 volts, pinio 17, gear 60, ratio 3.53, wheels 33 in.

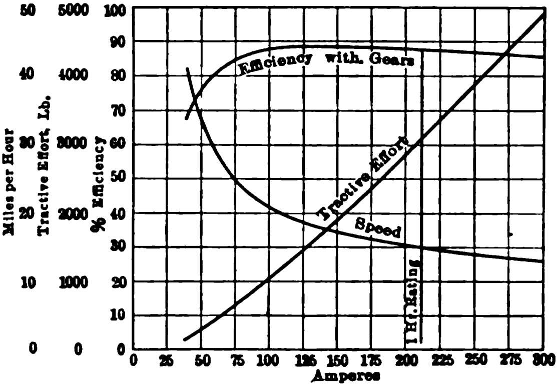


FIG. 11.—General Electric No. 66 railway motor. 125 h.p., 500 volts, pinion 17, gear 61, ratio 3.59, wheels 33 in.

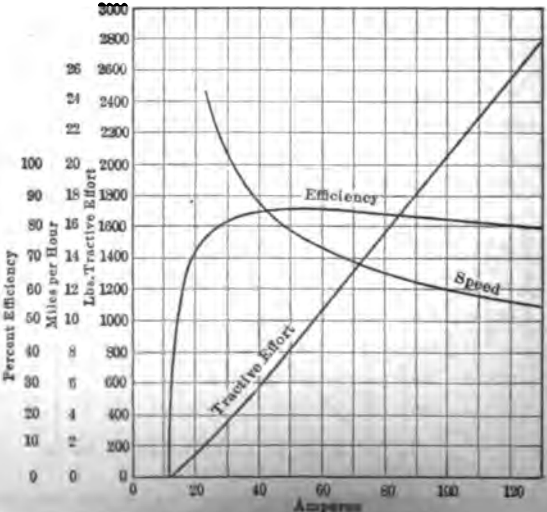


FIG. 12.—General Electric No. 203 railway motor. 50 h.p., 600 volts, pinion 15, gear 69, ratio 4.60 wheels 33 in.

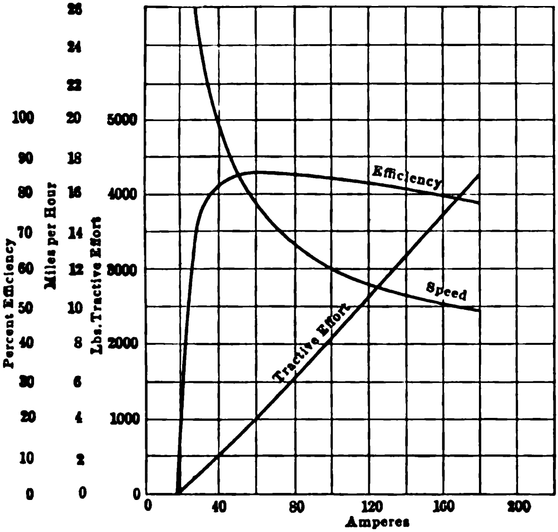


FIG. 13.—General Electric No. 210 railway motor. 70 h.p., 600 volts, pinion 16, gear 71, ratio 4.43, wheels 33 in.

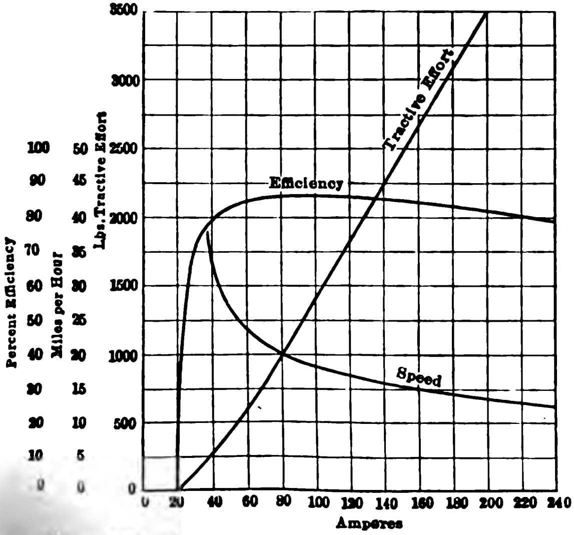


FIG. 14.—General Electric No. 214 railway motor. 75 h.p., 600 volts, pinion 17, gear 60, ratio 3.53, wheels 33 in.

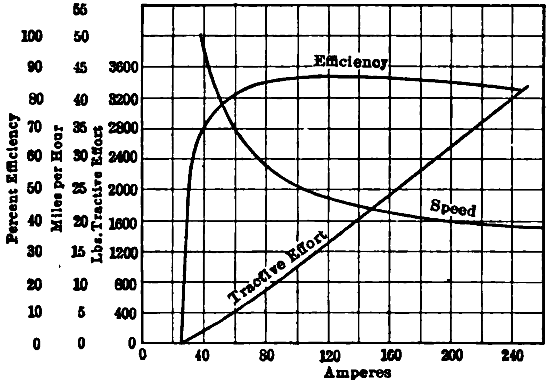


FIG. 15.—General Electric No. 205-*B* railway motor. 100 h.p., 600 volts, pinion 17, gear 57, ratio 3.35, wheels 33 in.

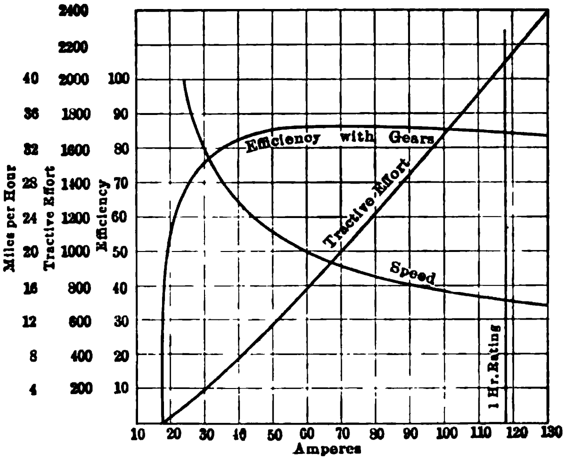


FIG. 16.—General Electric No. 205-*A* railway motor. 80 h.p., 600 volts, pinion 17, gear 67, ratio 3.35, wheels 33 in. Wound for operating two in series on 1200 volts.

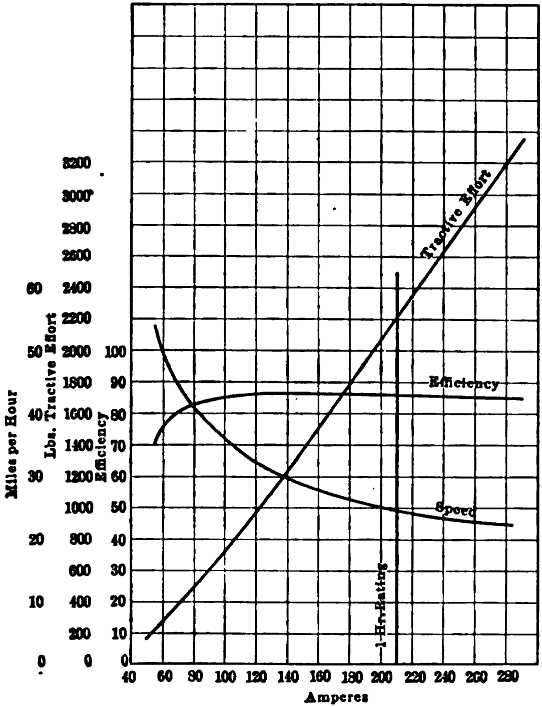


FIG. 17.—General Electric No. 207-*A* railway motor. 140 h.p., 600 volts, pinion 22, gear 59, ratio 2.68, wheels 36 in. Wound for operation two in series on 1200 volts.

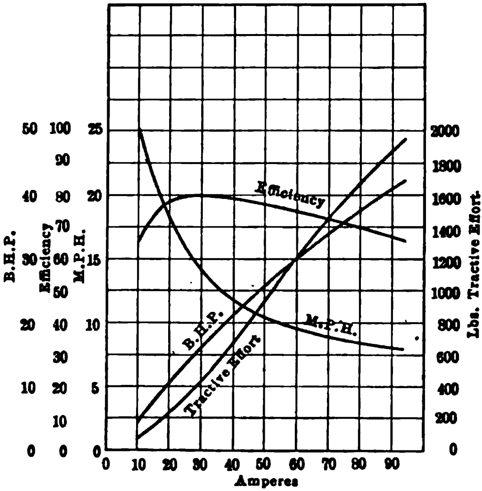


FIG. 18.—Westinghouse No. 12-*A*-25 railway motor. 25 h.p., 500 volts, pinion 14, gear 68, ratio 4.86, wheels 33 in.

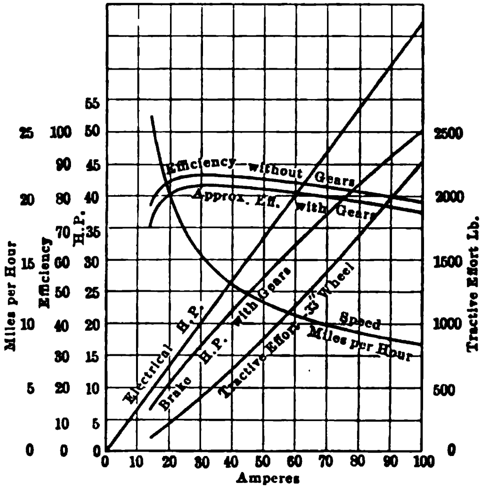


FIG. 19.—Westinghouse No. 69 railway motor. 30 h.p., 500 volts, pinion 14, gear 68, ratio 4.86, wheels 33 in. Continuous capacity 25 amp. at 300 volts, 23 amp. at 400 volts.

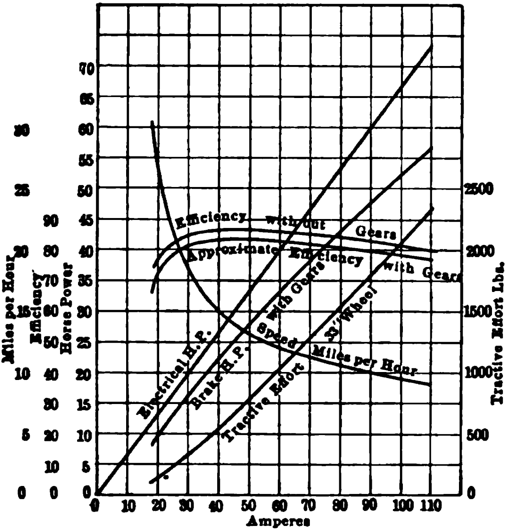


FIG. 20.—Westinghouse No. 49 railway motor. 35 h.p., 500 volts, pinion 14, gear 68, ratio 4.86, wheels 33 in. Continuous capacity, 30 amp. at 300 volts, 28 amp. at 400 volts.

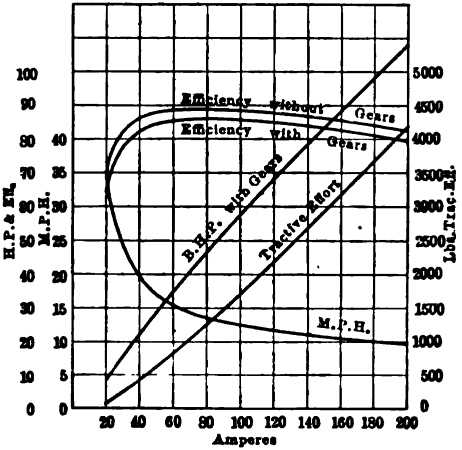


FIG. 21.—Westinghouse No. 93-*A* railway motor. 60 h.p., 500 volts, pinion 17, gear 70, ratio 4.12, wheels 33 in.

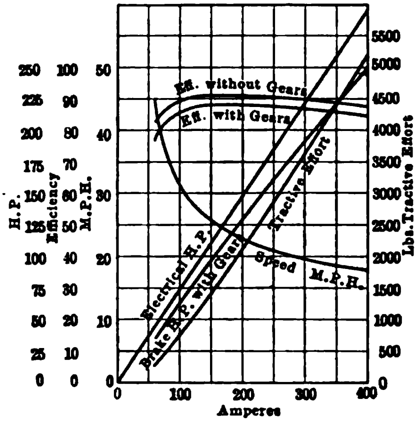


FIG. 22.—Westinghouse No. 119 railway motor. 125 h.p., 550 volts pinion 20, gear 55, ratio 2.75, wheels 33 in. Continuous capacity, 95 amp. at 300 volts, 85 amp. at 400 volts.

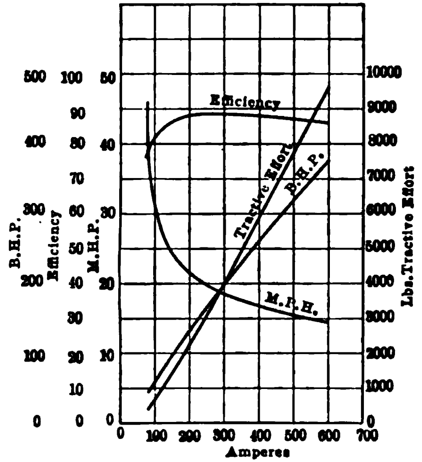


FIG. 23.—Westinghouse No. 113 railway motor. 195 h.p., 550 volts, pinion 19, gear 64, ratio 3.37, wheels, 36 in.

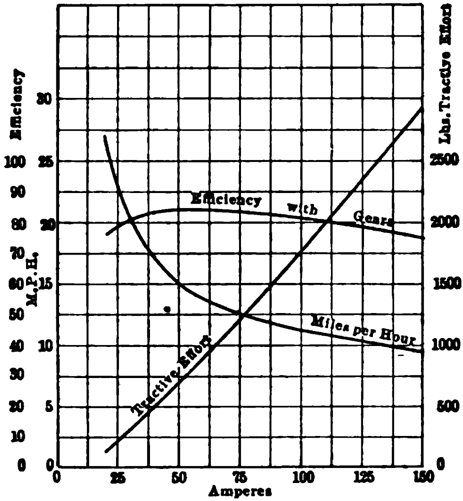


FIG. 24.—Westinghouse No. 101-*B* railway motor. 40 h.p., 500 volts pinion 17, gear 67, ratio 3.94, wheels 33 in.

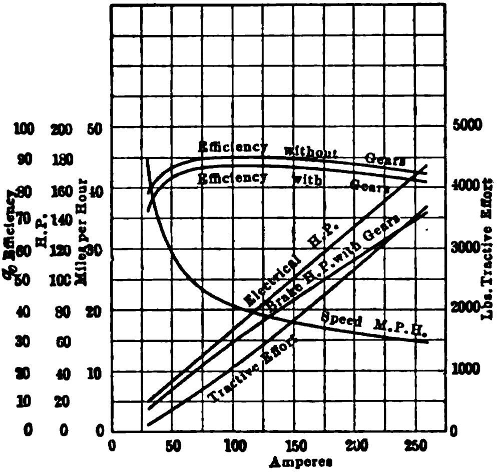


FIG. 25.—Westinghouse No. 112-*B* railway motor. 75 h.p., 500 volts. pinion 19, gear 70, ratio 3.68, wheels 36 in. Continuous capacity, 60 amp, at 300 volts, 55 amp. at 400 volts.

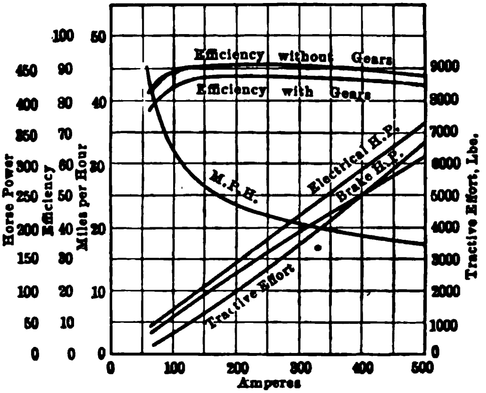


FIG. 26.—Westinghouse No. 114 railway motor. 160 h.p., 550 volts, pinion 20, gear 57, ratio 2.85, wheels 33 in. Continuous capacity, 120 amp. at 300 volts, 110 amp. at 400 volts.

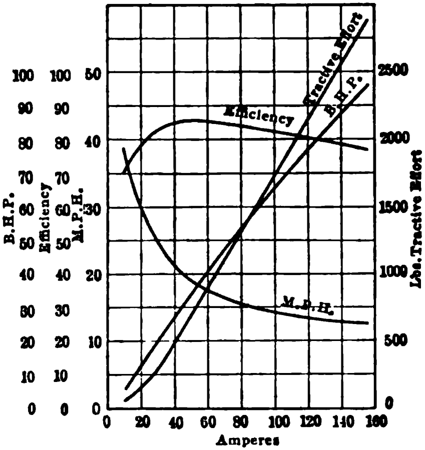


FIG. 27.—Westinghouse No. 319-*B* railway motor. 50 h.p., 600 volts, pinion 17, gear 69, ratio 4.06, wheels 33 in.

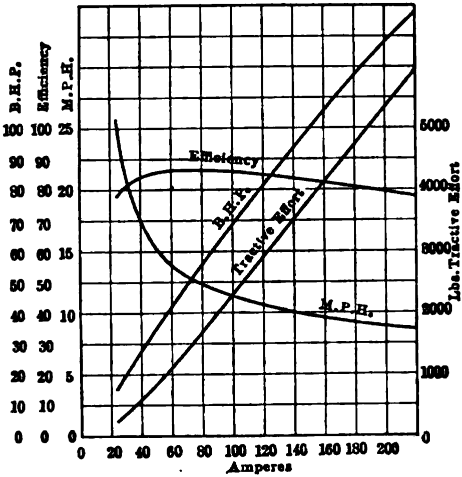


FIG. 28.—Westinghouse No. 316 railway motor. 75 h.p., 600 volts, pinion 15, gear 71, ratio 4.73, wheels 30 in.

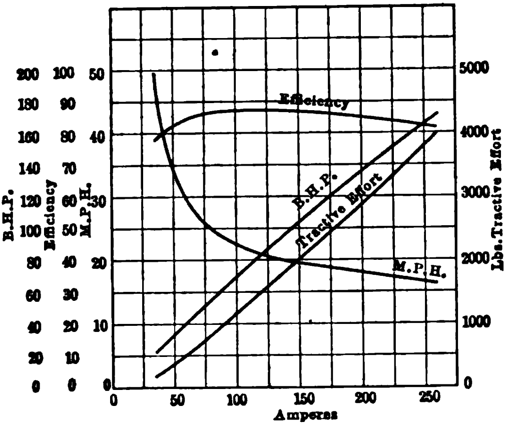


FIG. 29.—Westinghouse No. 317 railway motor. 90 h.p., 600 volts, pinion 19, gear 70, ratio 3.68, wheels 33 in.

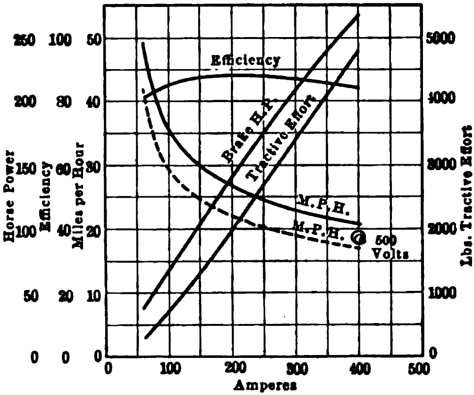


Fig. 30.—Westinghouse No. 302-*A* railway motor. 140 h.p., 600 volts, pinion 21, gear 56, ratio 2.67, wheels 36 in.

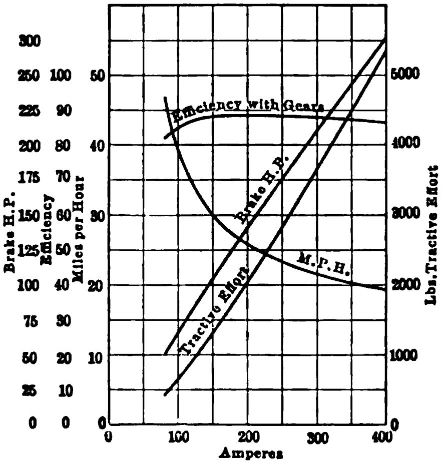


Fig. 31.—Westinghouse No. 301 railway motor. 175 h.p., 600 volts, pinion 18, gear 59, ratio 3.28, wheels 36 in.

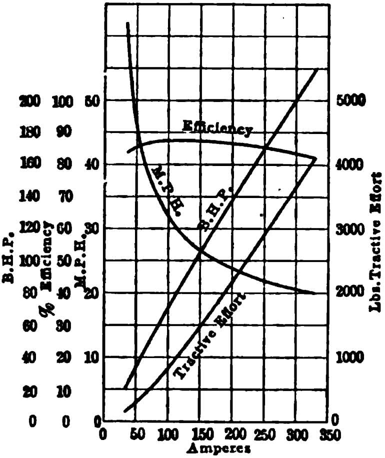


FIG. 32.—Westinghouse No. 333-*B* railway motor. 115 h.p., 600 volts, pinion 19, gear 58, ratio 3.05, wheels 36 in. Wound for operation two in series on 1200 volts.

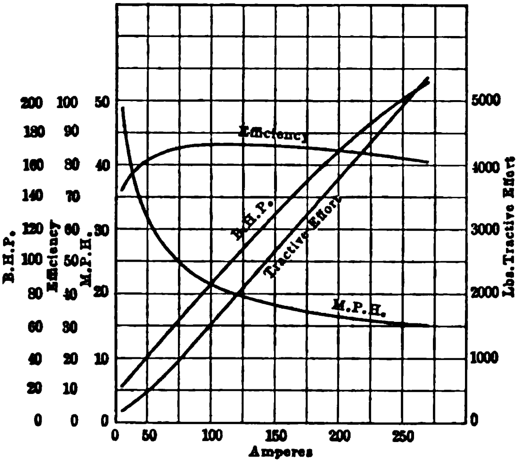


FIG. 33.—Westinghouse No. 321 railway motor. 110 h.p., 750 volts, pinion 16, gear 61, ratio 3.81, wheels 36 in. Wound for operation two in series on 1500 volts.

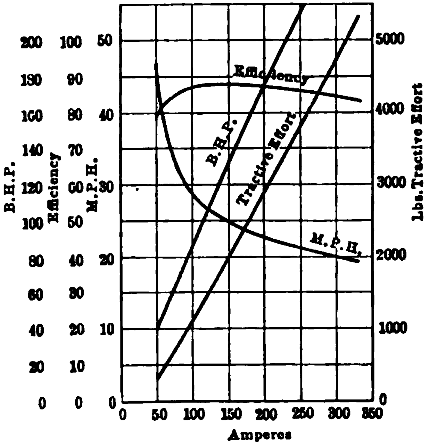


FIG. 34.—Westinghouse No. 322 railway motor. 140 h.p., 750 volts, pinion 16, gear 61, ratio 3.81, wheels 36 in. Wound for operation two in series on 1500 volts.

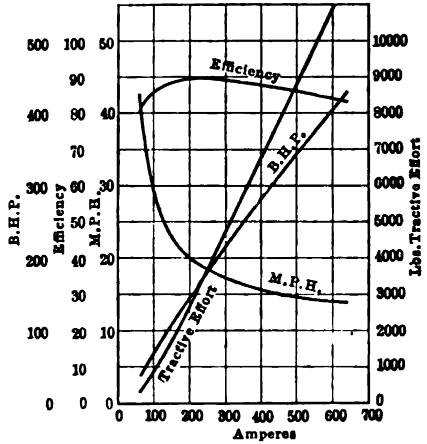


FIG. 35.—Westinghouse No. 308-*D* railway motor, 225 h.p. (250 h.p. with forced ventilation) 600 volts, pinion 19, gear 72, ratio 3.79, wheels 36 in. Wound for operation two in series on 1200 volts.

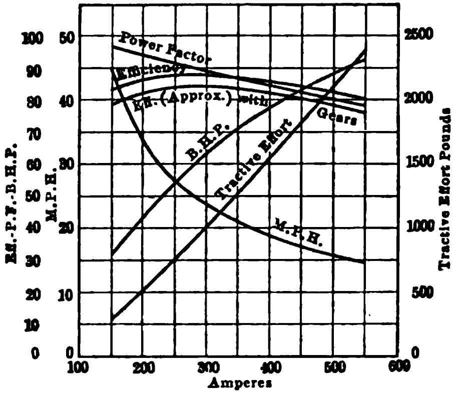


FIG. 36.—Westinghouse No. 135-*B* railway motor. 380 amp., 210 volts, 25-cycle, single-phase, alternating-current, pinion 17, gear 60, ratio 3.53, wheels 36 in. Continuous capacity 170 amp. at 130 volts.

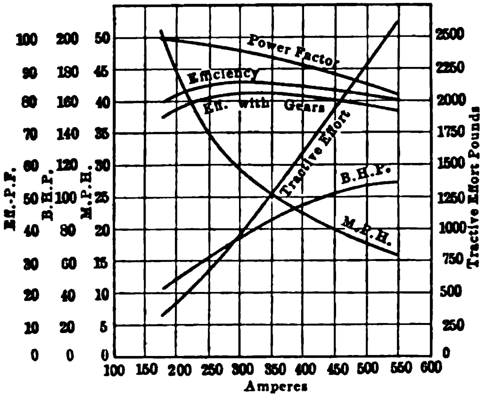


FIG. 37.—Westinghouse No. 132-*C* railway motor. 430 amp., 235 volts, 25-cycle, single-phase, alternating-current, pinion 20, gear 63, ratio 3.15, wheels 36 in. Continuous capacity 200 amp. at 235 volts.

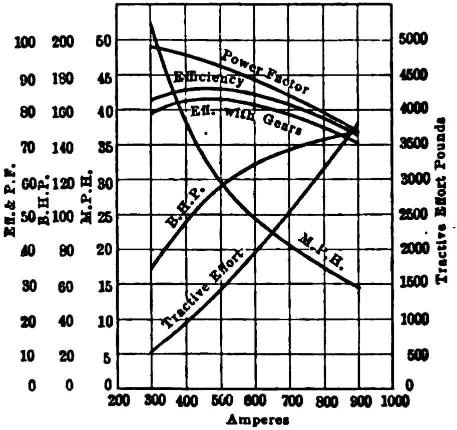


FIG. 38.—Westinghouse No. 148-*A* railway motor. 550 amp. (forced ventilation), 225 volts, 25-cycle, alternating-current, pinion 25, gear 66, ratio 2.64, wheels 38 in. Continuous capacity 325 amp. at 150 volts.

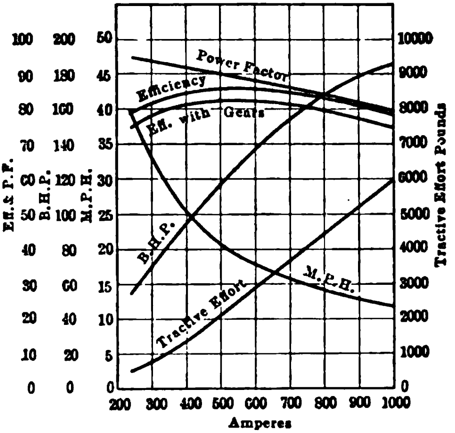


FIG. 39.—Westinghouse No. 133 railway motor. 600 amp. (forced ventilation), 235 volts, 25-cycle, alternating-current, pinion 17, gear 72, ratio 4.24, wheels 38 in. Continuous capacity, 600 amp. at 235 volts.

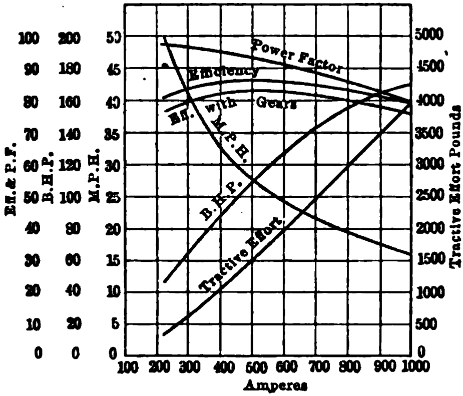


FIG. 40.—Westinghouse No. 156 railway motor. 600 amp. (forced ventilation), 210 volts, 25-cycle, alternating-current, pinion 25, gear 74, ratio 2.96, wheels 42 in. Continuous capacity, 450 amp. at 210 volts.

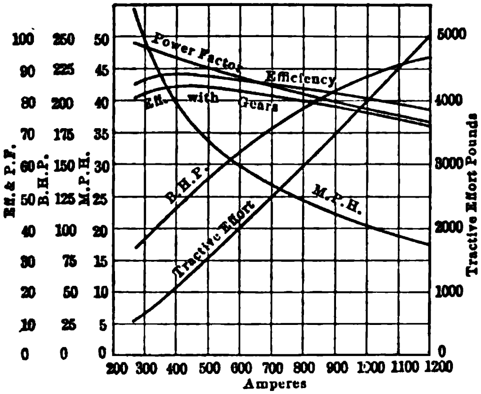


FIG. 41.—Westinghouse No. 409-*C* locomotive motor. 650 amp. (forced ventilation), 275 volts, 25-cycle, alternating-current, pinion 22, gear 92, ratio 4.18, wheels 63 in. Continuous capacity, 500 amp. at 275 volts.

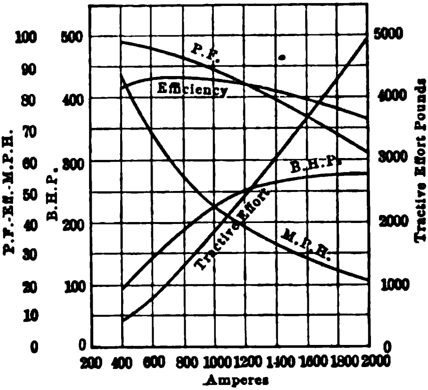


FIG. 42.—Westinghouse No. 130 locomotive motor. 1130 amp. (forced ventilation), 220 volts, 25-cycle, alternating-current, gearless, wheels 62 in. Continuous capacity, 860 amp. at 220 volts.

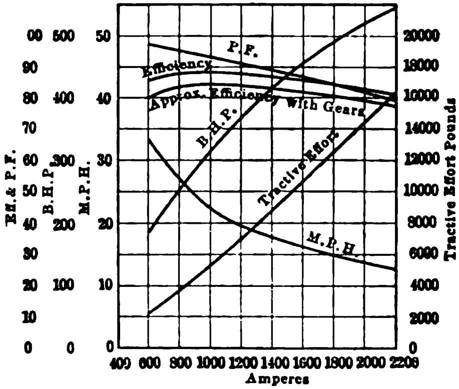


FIG. 43.—Westinghouse No. 403-*A* locomotive motor. 1000 amp. (forced ventilation). 300 volts, 25-cycle, alternating-current, pinion 24, gear 89, ratio 3.71, wheels 63 in. Continuous capacity, 930 amp. at 300 volts.

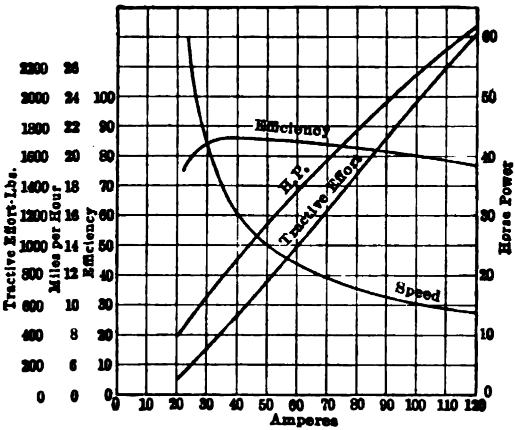


FIG. 44.—Allis-Chalmers No. 301 railway motor. 40 h.p., 500 volts, pinion 15, gear 69, ratio 4.60, wheels 33 in.

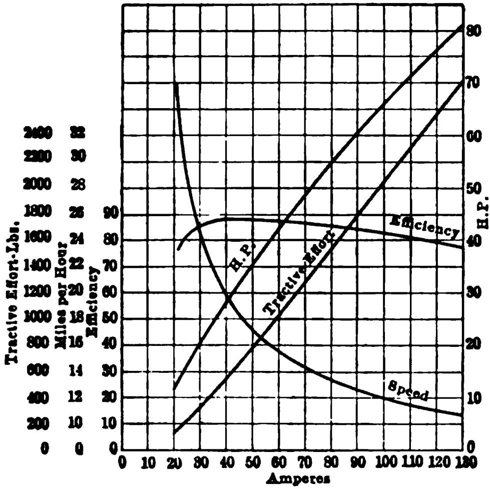


FIG. 45.—Allis-Chalmers No. 501 railway motor. 50 h.p., 600 volts, pinion 15, gear 71, ratio 4.73, wheels 33 in.

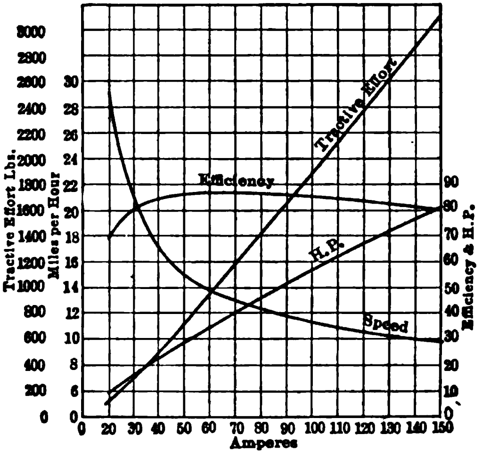


FIG. 46.—Allis-Chalmers No. 302 railway motor. 55 h.p., 500 volts, pinion 16, gear 73, ratio 4.56, wheels 33 in.

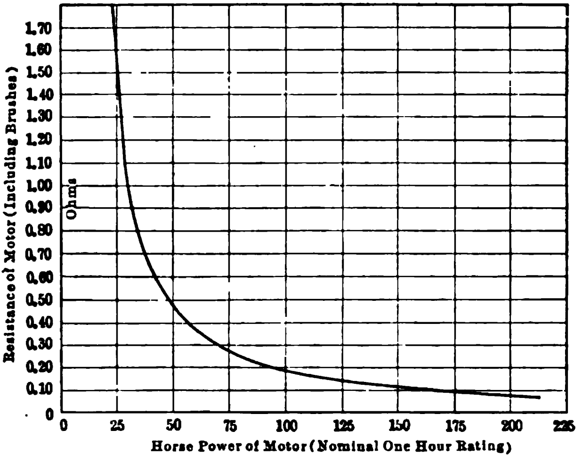


FIG. 47.—Approximate resistance of 500-volt direct-current motors at 75° C.

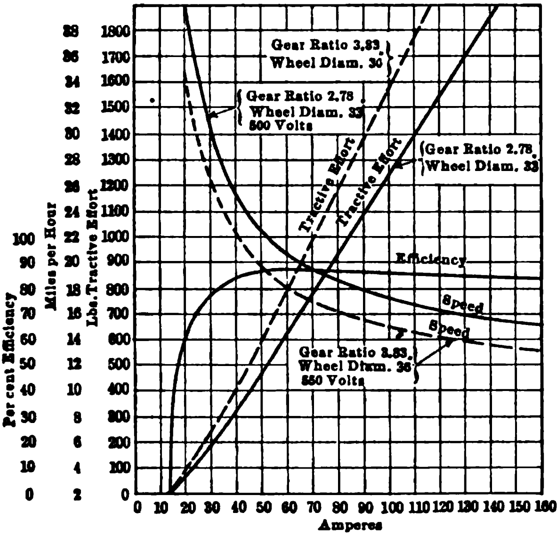


FIG. 48.—Illustrating change of tractive effort and speed curves for a change in gear ratio, driving wheel diameter and voltage. (GE-87 motor, 60 h.p.)

Alternating-current Railway Motors

General Structural Difference between Single-phase Commutating Alternating- and Direct-current Motors. The structural differences between single-phase alternating-current series motors and direct-current motors are summarized by Messrs. R. E. Hellmund and E. W. P. Smith in the Electric Journal, 1912, as follows:

(1) The laminated core of the alternating-current motor;
(2) Comparatively large number of poles of the alternating-current motor;
(3) The use of a distributed auxiliary winding on the alternating-current motor in addition to the main field winding;
(4) The larger armature diameter as compared with that of a direct-current armature;
(5) Short and stubby poles made possible by the small number of field ampere-turns on the alternating-current motor;
(6) The large and wide commutator of the alternating-current motor and the large number of segments as compared with direct-current machines;
(7) Small air gap of the alternating-current motor.

To these should be added preventive leads between the armature winding and commutator in the alternating-current motor.

The use of the laminated field structure, the auxiliary or compensating winding and the preventive leads in the single-phase motor are the differences essential to the single-phase motor.

Laminated Field Structure. The field is laminated in order to reduce the losses and associated heating due to the alternating flux in the iron.

Compensating Winding. The purpose of the compensating winding is to neutralize cross-magnetization, thereby improving commutation and power factor of the motor. Compensation is classified as conductive or inductive, depending upon the process by which the current flowing in the compensating winding is obtained. If the compensating winding is connected to receive current from an external source, as by connecting it in series with the main motor circuit, the compensation is said to be conductive. If the compensating winding is closed on itself so that a current due to a directly induced electromotive force flows within itself, the compensation is said to be inductive. On the New York, Westchester and Boston Railway inductive compensation is used. On the New York, New Haven and Hartford Railroad motors intended only for single-phase operation are inductively compensated. On the same road, motors intended for both single-phase and direct-current operation are conductively compensated. Insulation strain to ground is made negligible in the inductive compensation.

Inductive and Conductive Compensation. When motors operate only on alternating current the difference in results of either inductive or conductive compensation is inappreciable, but where the motor is to be operated with direct current, conductive compensation should be used.

Preventive Leads. Preventive leads in a single-phase commutating motor are added resistance between commutator windings and commutator bars. Their purpose is to restrict the current flowing in the armature coil when short-circuited by the brush. They add their resistance effect to that of the carbon brush bridging the commutator bars. In so restricting the current they improve commutation and they may improve the efficiency of the motor. Whether or not efficiency is improved by the preventive leads depends upon the balance of the following two effects: (*a*) I^2R loss due to the passage of the armature current through the preventive leads on its way to the armature winding. This loss varies directly with the resistance of the leads. (*b*) I^2R loss due to the passage of current set up in the short-circuited armature coil as a result of the electromotive force induced by the field. This loss decreases as the resistance of the preventive leads increases. The preventive leads are of greater value during starting and acceleration.

General Types of Single-phase Commutating Motors. There are three general types of single-phase commutating motors, namely, the series, repulsion and the induction series. Of these the former two are in most general use in America.

Connections of Single-phase Commutator Motors. The conventional diagrams, Figs. 49 to 55, inclusive, show some of the methods of connecting armature, field and compensating coils of single-phase commutator motors. Since the windings on armature and field of the repulsion motors are not electrically connected, operation of this type is possible on comparatively high voltages if the armature be so constructed that a low voltage is induced in it.

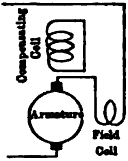


FIG. 49.—Inductively compensated series motor.

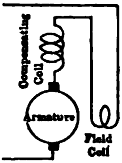


FIG. 50.—Conductively compensated series motor.

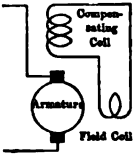


FIG. 51.—Induction series motor.

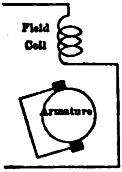


FIG. 52.—Thomson repulsion motor.

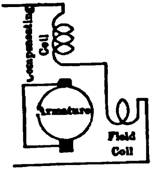


FIG. 53.—Series compensated repulsion motor.

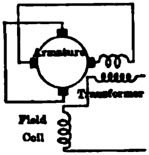


FIG. 54.—Winter-Eichberg repulsion motor.

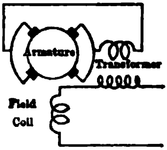


FIG. 55.—Latour repulsion motor.

Three-phase Induction Motor. The three-phase motor is called a constant speed motor (see p. 383 for methods of changing speed). It has the characteristics of a direct-current constant speed motor. Neglecting control, the speed of the three-phase induction motor depends upon the frequency of supply and the speed falls off but little as the load on the motor is increased. The speed of a train driven by three-phase induction motors ordinarily remains nearly constant up grade and down grade. The three-phase induction motor regenerates energy, forcing it back into the line when the motor is driven above its synchronous speed (see p. 213). This process takes place as the train descends a grade, and since this regeneration brings a load on the motor acting as a generator the train is not allowed to accelerate beyond the point at which the force due to gravity is balanced by the forces it is overcoming in driving the motor acting as a generator. Since the three-phase motor is a constant speed motor, in ascending a grade it will make a demand on the power station proportional to the torque required and the losses to the motor. As outlined on p. 214 this demand may, however, be reduced by the energy of regeneration of trains descending. In order to operate on long up grades a three-phase induction motor must have high continuous capacity.

The starting efficiency of three-phase motors is low so the motor is not well suited to service having frequent stops. The tractive effort may be held constant during the starting period, but this is done at the expense of energy lost in the motor-starting resistan

Since there is no electrical connection between the primary winding and the secondary winding of an induction motor, and there is no commutator, this type of motor may be built to operate on voltages which are high compared with those on which motors of other types are operated.

Speed of Induction Motor. The speed of an induction motor is equal to its synchronous speed minus the slip. The value of the slip increases at practically a constant rate from nearly zero at no load to about 2 to 5 or 6 per cent. of synchronous speed at full load.

$$S = \frac{f \times 60}{N}$$

in which S = synchronous speed, revolutions per minute
N = number of pairs of poles in the primary winding of the motor
f = frequency of applied electromotive force, cycles per second

$$S_1 = \frac{(100 - s)\,S}{100}$$

in which S_1 = actual speed of motor, revolutions per minute
s = slip, per cent.

TABLE OF SYNCHRONOUS SPEEDS

Number of pairs of poles in motor primary	1	2	3	4	5	6	7
Frequency, cycles per second	Synchronous speed, revolutions per minute						
15	900	450	300	225	180	150	128
25	1500	750	500	375	300	250	214
60	3600	1800	1200	900	720	600	514

Selection of Gear Ratio. In the following the gear ratio is the ratio of the number of teeth on the driven gear to the number of teeth on the driving motor pinion. The ratio of the number of revolutions of the motor shaft per unit time to the number of revolutions of the car axle driven by that motor is equal to the gear ratio. The speed at which a car having a given driving wheel diameter will be moved by given motors at a given current and electromotive force depends (neglecting the variation of train resistance) upon the gear ratio. If the gear ratio be *increased*, the speed of the car at a given current will be reduced, the tractive effort at the driving wheel treads will be increased, and the possible rate of acceleration will consequently be increased. If the gear ratio be *reduced*, the speed of the car at a given current will be increased, the tractive effort at the driving wheel treads will be reduced, and the possible rate of acceleration will consequently be decreased. Thus, with a low gear ratio, greater current will be required to produce a given tractive effort and acceleration than would be required with a higher gear ratio. (For effect of gear ratio and electromotive force on speed and tractive effort characteristics see p. 242.) The proper gear ratio to be used with a given car depends upon the service the car is to render and the character of the track over which it is to be operated. Whether or not the gear ratio once proper will be proper at a future time will depend upon whether or not the service requirements and character of the track remain constant; for example, a route may at one time require a few stops widely separated and on it high maintained maximum speeds may be permitted or necessitated; later this same route may require many stops close together, thus permitting only low maximum speeds. A gear ratio satisfactory in the first case would be unsatisfactory in the second. Frequently a car is required to give both city and suburban or interurban service or a combination of the three. It is in such cases that unsuitable gear ratios are probably most often used—the common error being to use a gear ratio lower than is necessary. This is brought about by not giving the requirements of city service due consideration while seeking high speeds. Unless field control be resorted to, a compromise based upon the different classes of service required must be made. Where it is possible to use field control the low speed service will largely determine the proper gear ratio. The proper gear ratio is the one with which, other things remaining constant, the required service is afforded at a minimum cost for energy and maintenance. As above noted, this will be determined by the conditions to be met, but in general the proper gear ratio is the highest with which the necessary schedule can be maintained (with allowance for low voltage and making up lost time) without establishing a dangerously high armature speed on descending grades. Various authorities have estimated that by the installation of proper gearing in existing equipments from 5 to 15 per cent. of the energy now used for traction could be saved. This saving is accompanied by a decrease in maintenance costs and the schedules are not impaired by the change. The following table from tests on the Brooklyn Rapid Transit System shows that by increasing the gear ratio a saving of 10 per cent. in energy consumption was secured and the original schedule was nearly maintained even though the number of stops per mile was increased.

	Tests made in 1905	Tests made in 1911
Average number of stops per mile	7.2	10.3
Average number of slow-downs per mile	7.9	7.2
Schedule speed, miles per hour	8.2	8.1
Weight of car, tons	16.22	18.11
Average passenger load, pounds	3040.00	2860.00
Weight of car and average load, tons	17.77	19.54
Seating capacity	38.00	38.00
Gear ratio	3.58	4.12
Watt hours per car mile	2672.00	2640.00
Watt hours per ton mile	150.4	135.1

Where stops are infrequent, as in suburban and interurban service, the possibility of maintaining comparatively high maximum speeds for a considerable length of time, together with the possibility of long coasting periods, make rapid rates of acceleration and braking of minor importance and a comparatively low gear ratio may be used to advantage. Where stops are frequent, as in city service, there is little or no opportunity for operation at high maximum speeds, high rates of acceleration and braking are necessary and there may be little opportunity for coasting. If a low gear ratio is to be used in such city service, a larger motor must be employed than would be necessary with a higher gear ratio and there will be a waste of energy. The use of a too low gear ratio with motors which would be large enough if a higher gear ratio were used causes the motors to operate in series or on resistance during a too great part of the time. This is equivalent to operating the motors on a voltage lower than normal. The motors are overloaded, and, in some cases, burned out, rheostats and controllers are overworked and, in some cases, generating stations and substations are greatly overloaded and the load factor is abnormally low. All this is accompanied by a waste of energy.

Figs. 56 to 61 by Mr. N. W. Storer, Electric Journal, 1908, show some of the effects of different gear ratios when applied to a certain motor equipment. The example is a specific one in which it is desired to determine the best gear ratio to use with equipment already in hand. In the preparation of these curves the following conditions were assumed:

Weight of car loaded	40 tons
Number of motors	4
Size of motors	75 h.p.
Line voltage	500 volts
Size of wheels	33 in.
Length of run	0.6 mile
Schedule speed	20 miles per hour
Length of stop	10 seconds
Rate of braking	1.5 miles per hour per second.

Figs. 56, 57 and 58 show the results obtained with a constant accelerating current of 138 amperes for all gear ratios. Figs. 59, 60 and 61 show the results obtained when accelerating at a constant rate of 1.5 miles per hour per second for all gear ratios. Fig. 56 shows the time required to run with power on, time for coasting and the time for the maximum accelerating current; or, in other words, the time for running on resistance. The time for the maximum

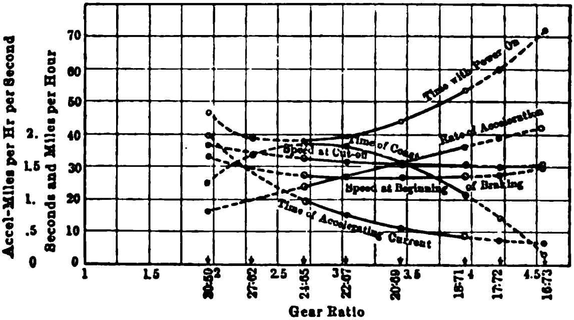


FIG. 56.—Typical performance curves of car with different gear ratios and constant accelerating current.

accelerating current varies from 37.5 seconds, with the 2:1 ratio, to 6.8 seconds with 4.5 : 1 gears. At the same time, the of acceleration varies from 0.8 mile per hour per second to 2.1 r

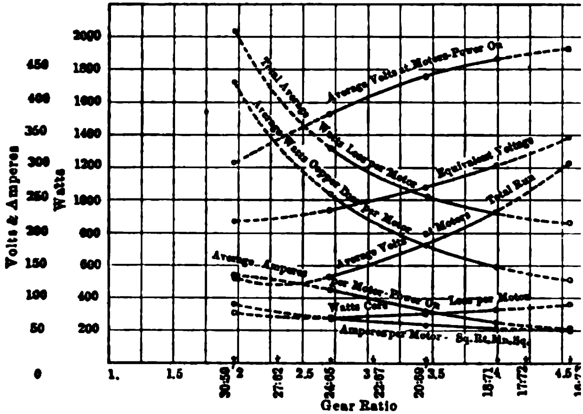


Fig. 57.—Typical performance curves of car with different gear ratio: constant accelerating current.

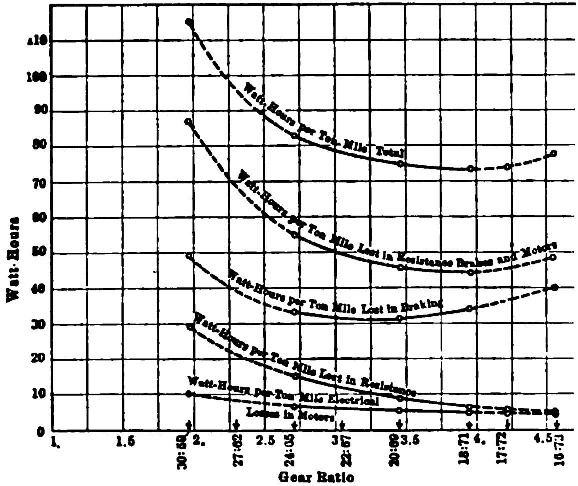


Fig. 58.—Typical performance curves of car with different gear ratio constant accelerating current.

per hour per second. Fig. 57 shows that the average voltage o motor while power is on is only 310 volts with 2 : 1 gears, whi rises to 480 volts with 4.5 : 1 gears. Motors are overloaded the voltage drops badly, and this is just as true when the average voltage applied to the motor is lowered by changing the gear ratio. This fact will be more readily appreciated when it is seen that the average rate of taking current from the line is 130 amperes per motor with the 2 : 1 gear and only 52 amperes with the 4.5 : 1. The square root of the mean square current per motor is 87 amperes for the 2 : 1 gear and 49 amperes for the 4.5 : 1 gear. The curves show average watts loss in the motor in copper and iron and the total electrical loss. They show that the *motor losses* will be a minimum with the maximum gear reduction. (The maximum gear reduction possible for this schedule would not be commercial as there is ab-

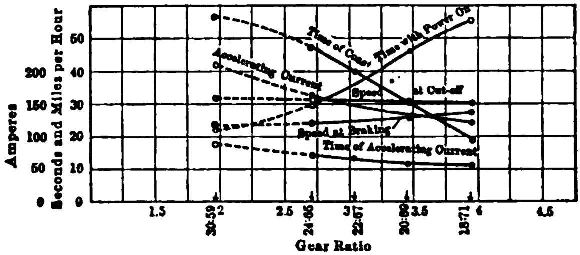


FIG. 59.—Typical performance curves of car with different gear ratios and constant rate of acceleration.

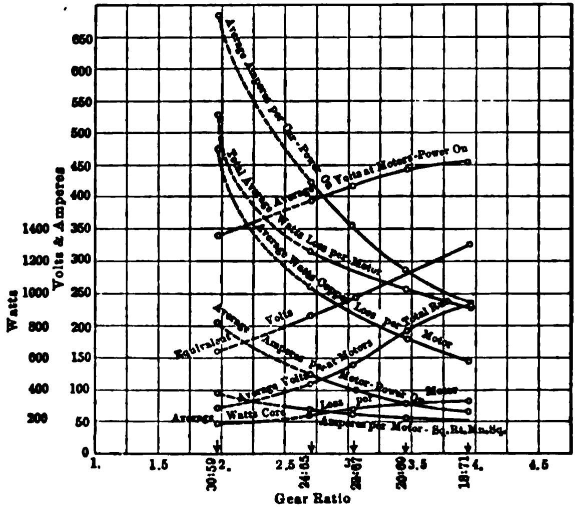


FIG. 60.—Typical performance curves of car with different gear ratios and constant rate of acceleration.

solutely no margin for making the schedule, but it is shown simply to point out the fact that the greater the gear reduction for a given schedule the lower will be the losses in the motor.) The curves in Fig. 58, however, show that the *energy consumption* is a minimum at about 4 : 1 gear reduction. The increase in watt-hours per ton mile between 4 : 1 and 4.5 : 1 is coincident with and due to the increase in speed at the time the brakes are applied, as shown in Fig. 56. The rise in watt-hours per ton mile with the 2 : 1 gear ratio is due to the increased loss in resistance and motors as well as in the brakes. The motor loss, it will be seen, is controlled almost entirely by the square root of the mean square current, as the iron loss is small at all times and remains close to 300 and 350 watts for all gear ratios. Fig. 59 corresponds to Fig. 56, Fig. 60 to Fig. 57, and Fig. 61 to Fig. 58. A comparison of these curves indicates that while a constant rate of acceleration produces a nearly constant energy consumption per ton mile, the motors will be very much more overloaded with the lower gear ratios at the *constant rate of acceleration* than when accelerating at the *constant current*. This would be apparent only in commutation, since the total losses in the motor, for any given gear ratio, will be approximately the same, as seen in Figs. 57 and 60, regardless of the rate of acceleration. This is probably true only within narrow limits.

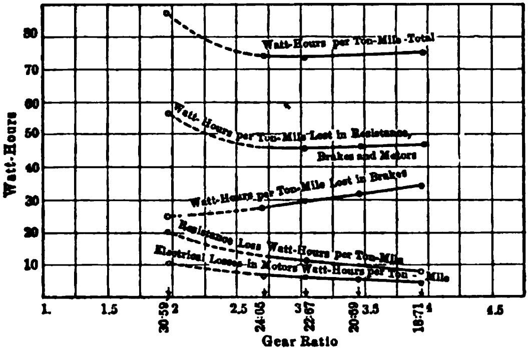


FIG. 61.—Typical performance curves of car with different gear ratios and constant rate of acceleration.

Limiting Armature Speed. In a paper by Messrs. N. W. Storer and G. M. Eaton, A.I.E.E., 1910, it is stated that for economical designs it is not advisable to allow a maximum armature speed of more than 2 or 2.5 times the speed at which the motor develops its continuous rated power. If a greater ratio than this is required, the armature speed must be reduced. The weight and cost for a given continuous capacity will increase directly with this ratio.

Ventilation of Motors

The capacity of a railroad motor as limited by heating depends upon the rapidity with which the heat can be carried from its origin to the surroundings of the motor. The heat generated in the armature and commutator together with a part of that generated in the field coils and cores is conducted to and radiated into the air within the motor. It is then carried on by convection and ventilation (natural or forced) directly to the outside air or to the motor frame through which it, together with a part of the heat generated in the field coils and cores, is conducted to the air surrounding the motor. The worst condition in this connection exists when the motor is closed and there is no ventilation or circulation of air tending to distribute the heat within the motor. Ventilation may be classified into natural and forced. These may be further subdivided as follows:

- (*a*) Natural
  - Internal circulation.
  - Circulation of outside air.
- (*b*) Forced
  - Blower within the motor.
  - Blower outside motor.
    - Internal circulation.
    - Circulation of outside air.

Internal Circulation. In this process the heat is distributed by keeping the warm air stirred up through the ducts and by the inherent windage of the motor. This aids in eliminating hot spots in the windings. This internal circulation may be forced by "blowers" (fans) built on the armature shaft.

Natural Circulation of Outside Air. This method is most used during warm weather and when the absence of moisture or great amounts of dirt allows the interior of the motor to be opened to the outside air. The motors are operated with perforated covers or with covers removed. The results are quite satisfactory.

Forced Circulation of Outside Air by Blower within the Motor. In this method a fan is mounted on the armature shaft at the pinion end of the armature and inside the motor. This fan drives air out of the motor through openings in the pinion end of the motor and outside air rushes through a screened opening, over the armature and field coils, under and through the commutator and then through longitudinal ducts in the armature core. When the car comes to a standstill the forced ventilation ceases. The course taken by the air in a typical direct-current motor employing this method of ventilation is indicated in Fig. 62. Relative to this motor, it is stated in the Electric Railway Journal, 1912, that when completely enclosed and with no external ventilation, the motor will perform a service similar to ordinary standard motors of the same hourly rating but of much greater weight. The same article states that a four-motor equipment run closed in interurban service on 600 volts will handle a car weighing 24 tons, at 22.5 miles per hour with one stop per mile. With external ventilation it will handle a car weighing 34 tons in the same service with the same temperature rise.

Forced Circulation of Outside Air by Blower Outside Motor. The method consists in forcing outside air through the motor from a separate motor-driven blower. An advantage of this method over all the others noted is that the circulation may be made to continue while the train is standing. It also assures clean, dry, ventilating air. This method is most commonly used on locomotives. On each 1500-volt locomotive of the Piedmont Traction Company a blower is mounted on the dynamotor shaft, and from the blower the air is conducted to the motors through proper conduits The dynamotor is also used to drive the air compressor. An example of the satisfactory application of this method to motor cars is found in the cars of the Pennsylvania R. R. for use on Long Island and through tunnels. The blower outfit consists of a 1½ h.p. 2250-r.p.m. motor, to the shaft of which is attached, at each end, a blower fan 9 in. in diameter and 3 in. wide. Each of these fans is capable of forcing between 400 and 500 cu. ft. of air per minute through the motor to which it is connected. The traction motors are interpole motors normally rated at 215 h.p., but by the ventilation they are enabled to do work which would otherwise require motors rated at about 250 h.p. each. The No. 0.69 ("Colonial Type") New Haven locomotive has eight compensated series type single-phase motors nominally rated at 170 h.p. each, and having a continuous rating of 145 h.p. Forced ventilation for cooling these motors and the main transformer is secured by means of two blower motors mounted under the cab and between the trucks. Each blower set consists of a 7.5 h.p. single-phase motor and a 20-in. Sirocco fan which can deliver approximately 6000 cu. ft. of air per minute. Due to truck movement and retricted space there are difficulties in applying this method to ordinary urban and interurban cars.

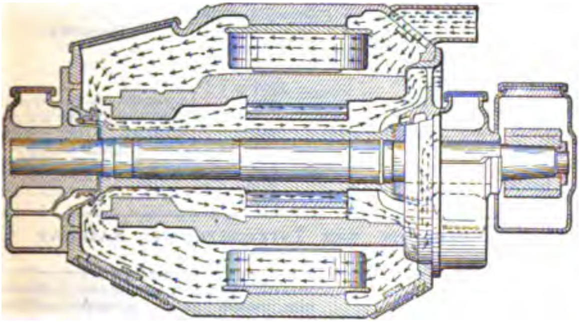


FIG. 62.—General Electric motor cooled by forced ventilation.

Commutator

Material and Construction (A.E.R.E.A. Approved Practice). Hard-drawn copper is recommended for commutators as possessing greater uniformity in size and hardness over the forged bars and corresponding superiority in life and service. Attention is also called to the importance of material and workmanship in the construction of commutators being such as to insure a solid structure which will not shrink, become loose, or get out of true. Built-up mica is preferable for commutator segments, but it is very important that the building-up should be even and compact. Assembled commutators should be baked at 230 deg. C. and compressed while hot to insure solidity, clamps being tightened before pressure is released.

Commutator Insulation Test. Bar to bar test recommended in Report of Committee on Electrical Equipment, A.E.R.E.A., 1907.

New commutators—220 volts d.c. 5 seconds.
Old commutators—110 volts d.c. 5 seconds.

Commutator Wear. The following two tables are from the report of the 1909 Committee on Equipment, A.E.R.E.A.

(1) MOTORS USED IN DENVER

Type motor	Commutator diameter, new, inches	Commutator diameter, scrapped, inches	Remarks
GE-53	12	10¼	
GE-58	10¾	8½	Increased ¾ in. diameter over original factory size.
GE-800	10⅛	7½	Increased 1 in. diameter over original factory size.
W.P. 50	7	5¼	
West. 101 F	10⅛	8 7/16	
West. 3	8½	6¾	

(2) MOTORS USED ON THE INTERNATIONAL RAILWAY CO., BUFFALO

Type motor	Commutator diameter, new, inches	Commutator diameter, scrapped, inches
GE-57	10¼	8⅝
GE-67	9⅛	7⅛
GE-74	11 3/16	8¾
GE-80	9⅝	7¼
GE-800	9⅛	7¾
GE-1000	8⅜	6⅝

The wear on a commutator is due to the friction between brush and commutator and the burning away of material by sparking, both of which are increased by vibration. The wear due to friction increases and the burning away of brush and commutator decreases with an increase of brush pressure. Mr. C. W. Squier, Electric Railway Journal, 1909, states that tests have shown that in service the wear due to burning is much greater than the wear due to friction and, as a result, the wear of the commutator and brushes follow each other; that is, the brush which wears most rapidly also produces the greatest commutator wear. He gives the following average figures for five different types of brushes, a number of each type having been installed for test purposes. The brush tension was from 5.2 lb. to 6.4 lb. per square inch of brush contact surface:

Brush wear per motor per 1000 car miles, inches	Reduction in circumference of commutator per 1000 car miles, inches
0.648	0.089
0.63	0.0817
0.54	0.0745
0.188	0.0084
0.111	0.0065

(To obtain the wear per brush, divide the figures by 6.)

Cost of Commutator Manufacture. The following table from Electric Railway Journal, 1910, is for commutators manufactured in the shops of a Canadian railway company using drop-forged commutator bars.

Cost of Complete Commutators

West.-3 motor

Commutator bars, 47½ lb., at 27½ cents	$13.06
Mica, 3¾ lb., at $1.75	6.56
Four mica circles, at 75 cents each	3.00
One flat mica ring, at 70 cents each	0.70
One vulcabeston ring, at 65 cents each	0.65
Commutator shell (labor included)	3.00
Labor	1.65
	$28.62

WP-50 motor

Commutator bars, 32 lb., at 27½ cents	$8.80
Mica, 3¾ lb., at $1.40	5.25
Two mica circles, at 70 cents each	1.40
Two mica circles, at 75 cents each	1.50
Commutator shell (labor included)	3.00
Labor	1.65
	$21.60

GE-800 motor

Commutator bars, 39½ lb., at 27½ cents	$10.86
Mica, 3¾ lb., at $1.40	5.25
Four mica circles, at 70 cents each	2.80
One flange mica ring, at $1.35 each	1.35
One vulcabeston ring, at 85 cents	0.85
Commutator shell (labor included)	3.00
Labor	1.65
	$25.76

GE-100c motor

Commutator bars, 49½ lb., at 27½ cents	$13.61
Mica, 4 lb., at $1.75	7.00
Two mica circles, at 85 cents each	1.70
Two mica circles, at 90 cents each	1.80
Commutator shell (labor included)	3.00
Labor	1.65
	$28.76

GE-67 motor

Commutator bars, 55½ lb., at 27½ cents	$15.26
Mica, 4 lb., at $2.00	8.00
Two mica circles, at 90 cents each	1.80
Two mica circles, at 95 cents each	1.90
Commutator shell (labor included)	3.00
Labor	1.65
	$31.61

GE-80 motor

Commutator bars, 69½ lb., at 27½ cents	$19.11
Mica, 4¼ lb., at $2.50	10.62
Two mica circles, at $1.15 each	2.30
Two mica circles, at $1.10 each	2.20
Commutator shell (labor included)	3.00
Labor	1.65
	$38.88

Commutator Manufacture. Following is an outline of the process of constructing and finishing a commutator in a railway shop: (1) Bars assembled in four-piece clamping plate (Fig. 63 is typical); (2) mica inserted; (3) bars squared and clamps tightened; (4) bars bored in lathe chuck; (5) tested for short circuit; (6) bars fastened to commutator core; (7) clamps removed; (8) tested for short circuit; (9) baked over gas to soften mica; (10) commutator tightened, then allowed to cool; (11) face turned; (12) bars slotted for leads; (13) tested for short circuit; (14) pressed onto armature shaft at 3 to 7 tons pressure; (15) locked to shaft; (16) slotted.

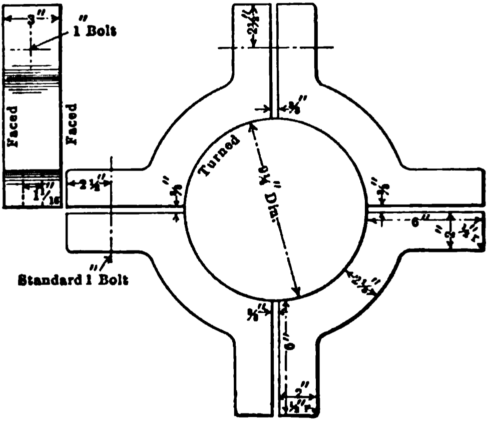


Fig. 63.—Clamp for GE-800 commutators.

Repair of Commutator by the Use of Water Glass. When a short circuit occurs between two bars in a commutator at or near its outer surface, the conducting material connecting the bars is generally removed by means of a sharp tool. Since this will disturb more or less of the mica, a small crevice will be formed between the segments. This crevice may be filled with waterglass, which solidifies and provides a good bearing surface, besides acting as an excellent insulation.

Commutator Defects Causing Bad Commutation. Mica high, bars high, bars flat, bars improperly spaced, surface dirty, short circuits between bars, commutator not true, commutator vibrating, commutator slipping on shaft.

Purpose and Advantage of Commutator Slotting. The purpose of slotting (also known as undercutting or grooving) a commutator is to make the presence of high mica impossible, thus permitting the use of a softer brush of better conductivity and making better contact with the commutator than would be permitted if the brush were required to grind the mica surface even with that of the commutator bars. The slotting permits the use of mica which, due to its abrasive qualities, would be prohibitive in an unslotted commutator. The reduction in the grinding action between commutator and brush reduces the amount of copper and carbon dust tending to impair the insulation within the motor. The trouble from flashovers is also reduced. Not only are commutator wear and brush wear reduced, but there is a saving due to the reduction in expense, delay and inconvenience connected with removing and replacing armature, turning and repairing commutator or replacing a defective commutator with a new one. There is little to be gained by slotting the commutator on a motor where the brushes used have the abrasive qualities necessary to keep the mica down as fast as the copper is removed without abnormal wear of brushes and commutator, and where such brushes have sufficient conductivity for the service.

The following commutator wear data is from operation on the Louisville and Southern Indiana Ry.

Before slotting

Motor	
GE 57	Average mileage between turnings, 38,500
GE 1000	Average mileage between turnings, 17,000
GE 800	Average mileage between turnings, 12,000
GE 57	Average mileage per brush, 16,000, hard brush used
GE 1000	Average mileage per brush, 1,000, hard brush used
GE 800	Average mileage per brush, 800, hard brush used

After slotting

GE 57	Average mileage between turnings, 92,000
GE 1000	Average mileage between turnings, 68,000
GE 800	Average mileage between turnings, 42,500
GE 57	Average mileage per brush, 58,000, soft brush used
GE 1000	Average mileage per brush, 37,000, soft brush used
GE 800	Average mileage per brush, 22,000, soft brush used

Dimensions of Slot. The width of the slot should be equal to that of the mica between the commutator bar; that is, all the mica should be removed between the surface of the commutator and the bottom of the slot. The depth of the slot that can be most satisfactorily used will depend upon the ability to keep it clean. The shallow slot will be kept free from dirt and dust more easily, but the slotting would have to be done more frequently. The depth ranges from 1/32 in. to 1/8 in. in practice.

The data in the following table were compiled from information given by the Proceedings of the Am. El. Ry. Eng. Assn., also the Electric Railway Journal.

Road	Date	Depth of commutator slot, inches
Oneida Railway	1909	1/32
Seattle Electric	1909	1/16
Puget Sound Electric Ry	1909	3/32
Boston Elevated Ry	1910	1/16
Ohio Electric Ry	1912	1/16
Connecticut Co. (Hartford shops)	1912	1/16
Worcester Consolidated Street Ry	1912	1/16

Manufacturers have been slotting the commutators to a depth of about 3/64 in. In the Electric Railway Journal, 1912, it is stated that the commutators of the New Orleans Railway and Light Co. are slotted to a depth of from ¼ in. to ⅝ in. when the motors are received. After slotting, these commutators are heated with a gasolene blow torch and a mixture of plaster of Paris and shellac is smeared into the slot with a putty knife and allowed to cool. It is stated that this practice, while avoiding too frequent slotting, keeps carbon dust from packing between the bars. In discussion, Am. El. Ry. Eng. Assn., 1909, Mr. W. J. Harvie, then Chief Engineer of the Oneida Railway Co., mentioned having found little improvement by slotting commutators 1/16 in., but that slotting 1/32 in. permitted the overhauling period to be increased to 50,000 miles.

Slotting. The greatest satisfaction is reported from the use of the shaper and the circular saw. The latter is most used. The saw is belt driven, or driven by an electric motor, or a compressed air motor. In some instances, the slotting is done while the armature and commutator are mounted in a lathe; in other instances, a special stand is used to hold the armature and commutator during the process. Provision should be made to allow the cutter to cut uneven mica without cutting the commutator bars. A sharp instrument is used to clean out the slots. Compressed air is also used for cleaning and, incidentally, it assists in keeping the saw cool. The burr left at the edge of the slot during the slotting is removed by a sharp knife, a file, or by taking a very light finishing cut in the lathe. The saws in use for slotting have diameters of from 0.75 to 1.25 in. and are of the same thickness as the mica to be removed. They have from sixteen to thirty teeth (early saws had more teeth but were unsatisfactory). Saw speeds in use vary from 1000 to 2000 r.p.m. The time required to slot a commutator depends principally upon

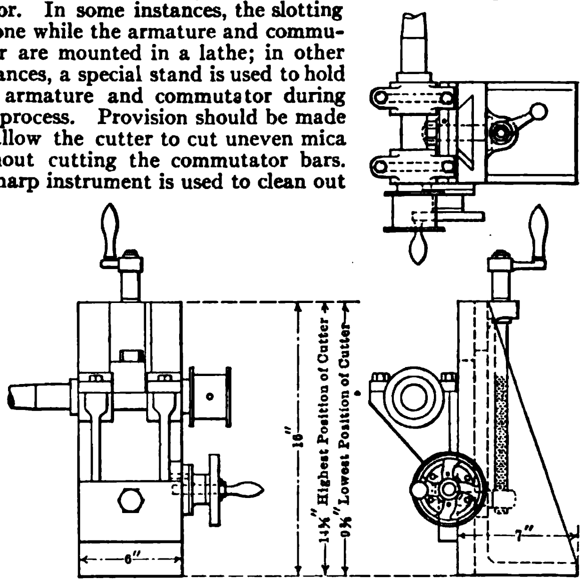

6"
16"
14⅝" Highest Position of Cutter
9⅝" Lowest Position of Cutter
7"

FIG. 64.—Commutator slotter for use on lathe, Boston.

the number of segments and the hardness of the mica in the commutator. Commutators have been reported to have been slotted in periods varying from 8.5 min. to 1 hour per commutator. Haste in slotting may lead to more trouble than existed before slotting. A few minutes may be well spent to insure a clean slot, free from burrs. It is very important that no thin layer of mica be left at the edge of the slot. An article by Mr. F. J. Foote, Ohio Electric Railway, in the Electric Railway Journal, 1912, states that a machinist's regular time for taking the preliminary cut on the commutator, slotting, taking the finishing cut and removing the burrs is 45 min. for a 73-bar commutator and 1 hour for a 205-bar commutator.

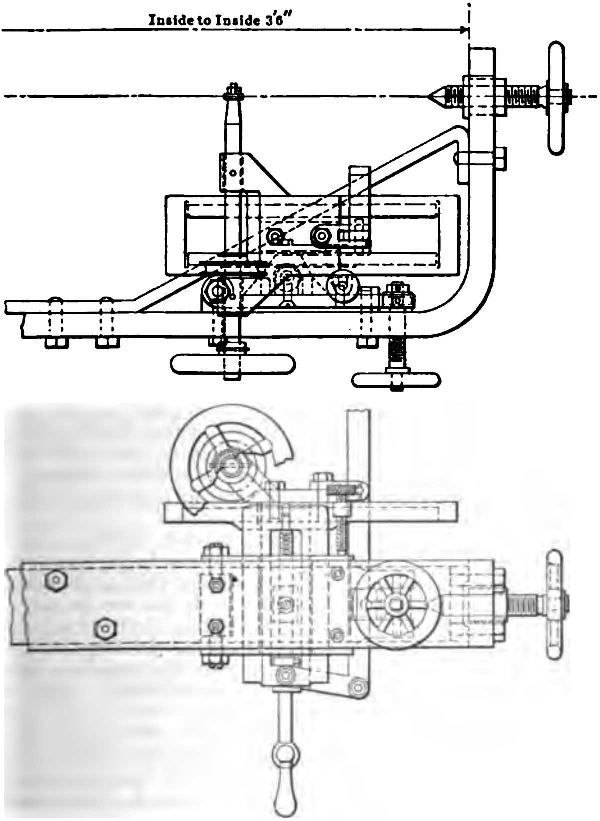


Fig. 65.—Commutator slotter for use on stand.

Fig. 64 shows the details of the commutator slotter used by the Boston Elevated Railway. The slotting tool is mounted on a shaft driven by a spindle carried in the bearing shown in the side elevation, and maximum facility of adjustment is afforded by the horizontal and vertical spindles illustrated. The cutting tool can be raised to a maximum height of 14⅝ in. above the ways of the lathe, and lowered to a height of 9⅜ in. above the bed. The maximum width of the frame supporting the tool and driving pulley is 7 in. The device is locked on the carriage of the lathe.

Fig. 65 shows the details of a commutator slotter for use on a stand. The center shown in the plan receives the commutator end of the armature shaft, the other center being at the opposite end of the stand. Adjustment for different sizes of commutators is obtained by a screw operated by a crank (shown at the bottom in the elevation). The downward motion is checked by the thumb screw. If the commutator segments are out of adjustment, adjustment to enable the saw to follow them is made by the small hand wheel at the right. In the process of slotting, the saw is advanced along the slot by a lever, a part of which is shown in the elevation.

Brush Holders

Brush Holder Faults Causing Defective Commutation. Following are some of the more common brush holder faults which lead to defective commutation: Improper brush position, improper spacing of brushes, vibration of brush gear, spring tension too great, brush pressure not radial tc commutator, sluggish action due to construction or friction or gummed parts (the last occurs most often when treated brushes are used), chattering, lack of sufficient bearing surface between brush and brush holder, bad fit (inherent or due to wear) between brush and brush holder.

Brush Setting by Trial. The correct brush position may be approximated by taking the speed of the motor in both directions with each of several brush settings. The setting which gives approximately the same speed in both directions is the one to use. In making this test, the brush should make contact over the same portion of its face while running in both directions, and there should be no brush play in the direction of rotation when the motor is reversed.

Brush Setting by Inspection on the Interpole Motor. Where the armature conductors can be traced from the commutator bars back under the poles, it is feasible in general to locate the correct setting by the position of the commutated coil with respect to the commutating poles. In standard practice the throw or span of the coil is made, as nearly as possible, equal to the pole pitch. In a parallel type of winding where the number of slots is an exact multiple of the number of poles, the space of the coil can be made exactly equal to the pole pitch. In this case, if the winding can be traced through, the brushes can be so set that a coil or turn exactly under the middle of the commutating poles has its two ends connected to the two adjacent commutator bars which are symmetrically short-circuited by the brush; that is, the mica between these two bars should be under the middle of the brush. To carry this out properly it is necessary to trace the conductor, with exactness, through the slots.

When there are several separate turns side by side in one slot, it is advisable to select a middle, or approximately middle, turn for determining the brush setting. When the correct brush setting has been found, the brush holder should be locked in this position. This care is very necessary with interpole motors.

Brush Pressure in Practice. The following table showing the practice of some of the principal electric railways in the United States, regarding brush tension per hammer, is from a paper by Mr. C. W. Squier, Brooklyn Rapid Transit Co., Electric Railway Journal, 1909:

Boston Elevated Railway Company	6 to 7 lb.
Brooklyn Rapid Transit Company	6½ to 8 lb.
Capital Traction Company, Washington, D.C.	4½ to 5½ lb.
Chicago City Railway Company	about 6 lb.
Chicago Railways Company	no standard.
Cincinnati Traction Company	no standard.
Hudson & Manhattan Railroad Company	4½ lb.
Interborough Rapid Transit—New York Subway	6 to 8 lb.
Interborough Rapid Transit—Manhattan Elevated	4 to 6 lb.
International Railway Company, Buffalo:	
General Electric 1000 motors	7 lb.
General Electric 64 motors	4 lb.
General Electric 74 motors	4 lb.
General Electric 57 motors	7 lb.
General Electric 800 motors	4 lb.
Long Island Railroad Company	no standard.
Massachusetts Electric Company:	
General Electric 90 motors	9 lb.
All other motors	7 lb.
Metropolitan West Side Elevated Railway, Chicago	6 to 7 lb.
Milwaukee Electric Railway & Light Company	7 lb.
New York Central Railroad Company:	
Electric locomotives	8 lb.
Motor cars	6 lb.
Northwestern Elevated Railway Company, Chicago	4 lb.
Philadelphia Rapid Transit Company	8 lb.
Pittsburgh Railways Company	14 lb.
United Railways Company, St. Louis	no standard.
United Railways & Electric Company, Baltimore:	
Westinghouse 3 motors	4½ lb.
Westinghouse 12A motors	4½ lb.
Westinghouse 49 motors	5 lb.
Westinghouse 38 motors	4 lb.
Westinghouse 56 motors	6 to 6½ lb.
Westinghouse 101B motors	5 lb.
Westinghouse 101D motors	5½ to 6 lb.
General Electric 80 motors	5 to 5½ lb.
General Electric 90 motors	5½ to 6 lb.
General Electric 1000 motors	5½ lb.
General Electric 800 motors	6 lb.
Municipal Traction Company, Cleveland	7 lb. per sq. in.
South Side Elevated Railroad Company, Chicago	4½ to 5 lb. per sq. in.

"One-way" Armature. If the leads of an armature are not connected to the right commutator bars, that is, if leads are brought to bars in advance of or behind the correct bars, bad commutation may result, the motor may reverse, or it may operate satisfactorily in one direction but unsatisfactorily in the other direction. Similar operating results may follow from the slipping of the commutator.

Broken Commutator Leads. Following are conditions which have been found to be the direct causes of or causes contributing to the breaking of commutator leads: Laminations loose, commutator loose, material of winding faulty, too much manipulation of the ever, in making comparisons of brushes and giving indications which with past records will aid somewhat in making an approximate selection. The most satisfactory way of determining what brush is best suited for a particular work is to make actual service tests with several different kinds of brushes. The laboratory tests which follow were suggested in the same report:

Vibrator Test. This test is a purely mechanical one. The brush is subjected to a series of mechanical shocks to determine how tough or brittle the brush may be. The vibrator consists of a ratchet wheel, the principle of which is indicated in Fig. 66. The diameter of the wheel should be about 9¼ in. There should be eight teeth, the depth of each tooth being 1/16 in. Adjacent to the wheel a standard brush holder is mounted so as to allow the brush to bear on the wheel with a standard pressure of 7 lb. per square inch of the bearing surface or cross-section of the brush. The face of the ratchet wheel should be broad enough to take the widest brush. The ratchet or vibrator wheel may be belted from a line shaft or driven by a small motor. The speed of the ratchet wheel should be 250 r.p.m. With this speed the brush will receive 2000 blows per minute. The ratchet wheel revolves backward so as to slip under the brush, and drop the same down 1/16 in. as each tooth passes. The various classes of brushes should stand a certain number of revolutions of this vibrator wheel before breaking. The values given below for the different classes of brushes are suggested. It has been found that a brush which breaks badly in service will hardly run on this wheel more than 5000 revolutions, and one which is fairly satisfactory in service will run 20,000 to 50,000 revolutions. A brush which is of excellent mechanical quality will run 100,000 revolutions and show no breakage or chipping. It is suggested that class 1, coke brushes, should stand 20,000 revolutions on the vibrator wheel, that class 2, part coke and part graphite brushes, should stand 30,000 revolutions, and that class 3, graphite brushes, should stand 50,000 revolutions.

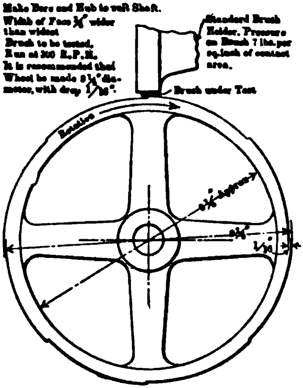

Make Bore and Hub to suit Shaft.
Width of Face ¼" wider than widest Brush to be tested.
Run at 250 R.P.M.
It is recommended that Wheel be made 9¼" diameter, with drop 1/16".
Standard Brush Holder. Pressure on Brush 7 lbs. per sq. inch of contact area.
Brush under Test
Rotation
9¼" before
9¼"
1/16"

FIG. 66.—Vibration test of carbon brushes.

Hardness Test. This test consists of comparing the hardness of carbon brushes with various standard "H" drawing pencils. It is recommended that the Johann Faber pencil be adopted as a standard of hardness. This test consists of scratching the brush with pencils of various hardness to determine which hardness of pencil corresponds to the hardness of the carbon brush.

Slip-ring Test. In this test the current is passed through the brush to a slip ring to determine the maximum amperes per square inch which the brush can carry without glowing. The current from the ring may be conducted by placing copper brushes on the hub of the slip ring. The slip ring should be a wheel of hard copper 8 in. in diameter with a rim ½ in. thick, and a width of face sufficient to test the widest brush. The wheel should be mounted and so arranged as to use a standard brush holder, the brush pressing against the slip ring as in the motor. The speed of the slip ring should be approximately 500 r.p.m. The slip ring may be driven from line shafting or from a small motor. The pressure per brush should be 7 lb. per square inch of bearing surface or cross-section. The periphery of the slip ring should have a true and smooth surface. The slip-ring wheel should run true so that the brush, when once fitted, will maintain a true and perfect-fitting surface. Twelve or fifteen samples of each quality of brush should be tested. The current should pass from the brush to the slip ring; that is, the brush should be positive to the ring. Direct current should be used. The maximum of 25 volts will be suitable for testing ordinary railway brushes. The following requirements were suggested by the Committee: Class 1, coke brushes, 100 amp. per square inch without glowing. Class 2, part coke and part graphite brushes, 150 amp. per square inch without glowing. Class 3, graphite brushes, 200 amp. per square inch without glowing.

Grading Brushes by Comparison. The following is from a statement by Mr. G. M. Hill, Assistant Engineer, Railway and Traction Department, General Electric Co., 1907: "It is a very easy matter to distinguish different grades of brushes by scratching with a knife, observing the ease with which they may be cut and the sound produced by scratching. A little practice will enable anyone to classify the brush as to its hardness. Aside from the matter of grade, it is important to detect certain faults in the brushes. Some of the faults are:

1. Spongy, or cellular construction, which is produced by overheating the squirting die, by insufficient pressure, or by the presence of a small amount of moisture when the brush is baked. This can be detected by the appearance of the brush or by scratching or cutting with a knife. Such brushes will weigh less than a brush of proper compactness. They will wear rapidly and produce an abnormal amount of dust and smudging on the commutator which results in flashing.

2. The stratified construction of the brush. When the brush is broken it will present the appearance of slate shale showing that the brush is apparently composed of a number of layers which are poorly joined together. This results from the outer layers sticking in the squirting die so that portions of the mixture slide over each other, and such a brush will easily chip off at the edges, affording an insufficient contact with the commutator and producing sparking and overheating. The best way to inspect for stratification is to break a small percentage of the brushes received, and if they show a stratified construction, the entire lot should be rejected. Often a stratified brush may be detected by examining the edge, but, unfortunately, some manufacturers have recently made a practice of covering the edge of the brush with a carbon paste which conceals the small cracks indicating stratification.

Double Width Brushes. Without making any general recommendations, the report of the Committee on Maintenance and Inspection, Am. El. Ry. Eng. Assn., 1908, suggests as follows, requesting each road to investigate and make its own conclusions in the matter: "It has been found advantageous on a number of roads to use one brush per holder, even though it necessitates cutting out the bridge in the brush box. The ridge in the middle of the commutator is avoided and, in most cases, longer life of the brush is obtained. Should there be irregularities of the commutator which would cause the brush to be thrown from the commutator, the entire circuit would be broken if one brush is used, and less flashing would be obtained by the use of two brushes; this is particularly true of high commutator speeds." In discussing double width brushes, Mr. Jeandron of Le Carbone Co. stated: "In regard to the subject of single and double width brushes I think that the advantage of single width brushes lies in a better distribution of the current, their fitting on commutators being more easily obtained on account of their smaller section. On the other hand, I believe that brushes can be found, the abrasion coefficient of which is low enough to practically avoid the ridge mentioned by the committee."

Limiting Speed for Carbon Brushes. Experience places the limiting peripheral commutator speed for carbon brushes in the neighborhood of from 6000 to 7000 ft. per minute.

Life of Brushes in Practice. The following statement occurs in a paper by Mr. Charles E. Eveleth, A.I.E.E., 1910: "On the Pittsburg, Harmony, Butler & Newcastle line where the service is unusually severe on account of grades and curves, a considerable number of the brushes originally shipped in the motor brush holders are still in service, though many motors have now run over 150,000 car miles, and the wear on the commutators is hardly perceptible."

Answers to the question, A.E.R.E.A. Question Box, 1911: What car mileage per inch wear are you obtaining from different kinds of carbon brushes. (*a*) On *non-interpole* motors with *unslotted* commutators? (*b*) On *non-interpole* motors with *slotted* commutators? (*c*) On *interpole* motors with *unslotted* commutators? (*d*) On *interpole* motors with *slotted* commutators?

Conestoga Traction Co., Lancaster, Pa. (*d*) National Carbon Brushes, superior quality, 18,000 miles.

H. W. Fuller, Washington Railway & Electric Co., Washington, D. C. (*b*) 3500 miles average. (*d*) Estimated 400,000 miles. We have some motors that have made over 100,000 miles and the brushes show less than ¼ in. wear.

Wm. A. House, The United Railways and Electric Co., Baltimore, Md. (*b*) Approximately 2500 miles per ⅛ in. of brush wear for average of large system covering many types. Side wear is the limiting factor.

J. F. Calderwood, Brooklyn Rapid Transit Co., Brooklyn, N. Y. (*a*) We are not operating non-interpole motors with unslotted commutators at the present time, but in tests made about 3 years ago we obtained an approximate mileage per inch wear of brushes of different types and on different motors as follows:

Type of motor	Type of brush	No. of miles per 1 in. wear of brush for brush worn out	No. of miles per 1 in. wear of brush considering all brushes, worn out, broken or chipped
E-150 h.p.	A	16,800	10,000
	B	20,000	9,369
	C	30,120	9,141
L-150 h.p.	A	7,100	2,900
	B	28,900	3,000
	C	22,800	4,100

(*b*) We have no recent data in regard to the wear of brushes on non-interpole motors with slotted commutators, but in tests made about 3 years ago the following wear was obtained:

Type of motor	Type of brush	No. of miles 1 in. wear of brush for brush worn out	No. of miles 1 in. wear of brush considering all brushes worn out broken or chipped
E-150 h.p.	A	14,800	3,672
	B	15,600	6,344
	C	17,100	2,145
	D	14,200	6,483
L-150 h.p.	A	21,600	3,850
	B	14,600	4,900
	C	6,900	5,300
	D	10,000	2,100

(*c*) On interpole motors with unslotted commutators, we are obtaining 132,000 miles per inch of wear of brushes which are worn out but when the number of broken and chipped brushes are taken into consideration, the mileage per inch of wear for all brushes removed is 11,775 miles.

C. D. Cass, Waterloo, Cedar Falls and Northern Railway Co., Waterloo, Iowa. We are using the Le Carbone brush grade G, on solid commutators and getting on an average 90,000 miles per 1 in. wear.

Richard McCulloch, United Railways Co. of St. Louis, St. Louis, Mo. (*a*) 11,000 miles. (*b*) 30,000 miles. (*d*) 250,000 miles.

F. G. Grimshaw, The Pennsylvania Railroad Co., Camden, N. J. We obtain ½ to ⅝ in. wear on motor brushes and an average of 28,000 miles.

H. M. Lloyd, British Columbia Electric Railway Co., Ltd., Vancouver, B. C. All our commutators are slotted. We have obtained the following mileage per inch wear of brushes:

GE-67 motor	17 : 67 gear ratio	1,706 car miles
WH-101B2 motor	15 : 69 gear ratio	1,280 car miles
GE-57 motor	22 : 65 gear ratio	7,979 car miles
GE-204 motor	20 : 65 gear ratio	23,922 car miles

A paper in the Electric Railway Journal, 1911, states that the life of a medium hard brush used by the Long Island Railway on slotted commutators is from 45,000 to 50,000 miles. These brushes are under a pressure of 6 lb. per square inch.

The following table is from brush tests lasting from May 14, 1908 until March 10, 1912 on the Third Avenue Railway, New York. The commutators used in these tests were slotted. (The letters A,B,C, etc., refer to the manufacturers of the brushes.)

ABSTRACT OF CARBON BRUSH RECORD OF THIRD AVENUE RAILWAY, NEW YORK

Brush	Motor	Installed	Last inspection	Mileage	Average wear in 64ths of an inch	Wear in inches, 1000 miles
A-1	GE-210	5/20/08	4/20/10	30,686	....	....
A-2	GE-210	5/14/08	3/10/11	45,280	....	....
B-1	GE-210	5/20/08	9/17/11	55,705	16	0.0045
B-2	GE-210	1/31/09	9/17/11	59,789	22	0.0057
B-3	W-310	1/26/11	9/17/11	14,489	....	....
B-3	W-310	1/26/11	9/17/11	18,904	10	0.0083
B-3	GE-210	1/26/11	3/10/12	25,684	12	0.0073
B-3	GE-210	1/26/11	9/17/11	32,084	5	0.0024
B-4	W-310	1/26/11	3/10/11	2,622	....	....
B-4	GE-210	1/26/11	9/17/11	18,305	6	0.0051
B-4	GE-210	1/26/11	9/17/11	13,771	7	0.0077
C-1	GE-210	7/30/09	3/10/12	45,077	18	0.0062
C-2	W-310	7/28/09	9/17/11	38,413	14	0.0057
D-1	GE-210	5/29/09	3/10/11	31,179	16	0.0080
D-1	W-310	5/29/09	12/1/09	15,286	8	0.0082
D-1	W-310	10/20/09	4/20/10	15,321	12	0.0120
D-1	W-310	10/20/09	3/10/11	44,206	....	....
D-1	W-310	10/22/09	4/20/09	13,226	12	0.0140
D-1	GE-210	5/29/09	9/17/11	49,192	25	0.0079
D-2	W-310	10/20/09	3/10/11	39,066	....	....
D-2	W-310	10/26/09	3/10/11	37,356	....	....
D-2	W-310	10/22/09	4/20/10	14,797	11	0.0120
D-2	W-310	10/20/09	7/20/10	23,640	13	0.0086
D-2	GE-210	5/29/09	3/10/11	45,927	16	0.0054
D-2	W-310	10/24/09	3/10/11	53,715	....	....
D-2	GE-210	5/29/09	9/17/11	58,420	20	0.0053
E-1	GE-210	5/10/10	3/10/12	41,537	17	0.0071
E-1	GE-210	5/10/10	9/17/11	29,340	9	0.0048
F-1	GE-210	9/16/10	3/10/11	11,831	16	0.0021
F-2	W-310	9/16/10	3/10/11	10,039	....	....
F-3	W-310	9/16/10	3/10/11	9,930	....	....
F-4	GE-210	1/16/12	3/10/12	6,400	5	0.0122
F-5	W-310	1/16/12	3/10/12	6,200	3	0.0075
G-1	W-310	9/19/11	11/24/11	....	....	....
G-1	W-310	9/19/11	3/9/12	....	....	....

Discussion of the brushes: A were satisfactory, the only trouble was evidence of uneven wear. B were easily chipped and broken. C were satisfactory. D, most of these were removed for breakage, chipping and uneven wear. E gave good service except that they blackened the commutator. F, most of these were removed because of breakage, chipping, uneven wear and wear on the commutator. G broke after short runs.

The width of most of the brushes was $2\frac{15}{64}$ in., but there were a few as narrow as $2\frac{13}{64}$ in. and one as wide as $2\frac{17}{64}$ in. The company's standard tension per brush holder spring is 6 lb. for the GE-210 motors and 5 lb. for the Westinghouse 310 motors.

Carbon Brush Costs. In discussion, Am. El. Ry. Eng. Assn., 1908, Mr. J. S. Doyle of the Interborough Rapid Transit Co., New York, speaking of a special brush used by that company, stated: "We have done about three billion miles of work per year and by using this special brush our troubles have been reduced 85 per cent. on the elevated division and about 96 per cent. on the subway division. The initial cost of the special carbon is considerably greater than that of the ordinary brush, but the actual cost as measured on a thousand-mile basis is $0.173 for the special carbon, as compared with $0.44 per thousand miles for the ordinary carbon, which is in addition to the improvements stated." In further discussion, Mr. Doyle stated that in all probability the special carbon would come under Class No. 3 (see p. 285, Classification of Railway Motor Brushes).

The following table from Electric Railway Journal, 1912, shows the carbon brush costs from August, 1911, when this item was first segregated, to March, 1912, inclusive, for all electric cars, except storage battery cars, operated by the Third Avenue Railway on its Third Avenue, Forty-second Street and Dry Dock divisions:

Mileage	Date	Cost
1,065,778	August, 1911	$27.82
1,019,762	September, 1911	....
970,229	October, 1911	49.34
955,499	November, 1911	23.11
964,307	December, 1911	8.66
913,982	January, 1912	14.83
930,199	February, 1912	38.89
1,031,208	March, 1912	18.75
7,850,964	....	$181.40

Cost: 2.31 cents per 1000 car miles.

Sparking at the Commutator of a Railway Motor. A great number of troubles in railway motor operation are due to sparking at the commutator. Most of them are cumulative or are climaxes of a cumulative action which, other things being constant, depend upon the service required of the motor. Starting with a polished commutator and a perfect brush, each spark will remove a particle of the commutator copper and possibly a bit of the brush. As this goes on, the contact between brush and commutator grows poorer, the brush vibrates minutely and the extent of the sparking increases. This causes poorer brush contact, increased brush vibration and sparking and grinds the brush rapidly. If the commutator be not slotted this removal of copper will leave the mica projecting above the commutator bars and all the effects just noted will be augmented. Hard brushes under a considerable pressure will grind the commutator. This grinding action continues while the armature revolves, and if the sparking is not too severe and the periods during which current flows not too long nor too great, compared with those during which the commutator is revolving with current off, this grinding action may remove the roughness and dress the brush between sparking periods. This process of grinding, however, shortens the lives of both commutator and brush.

Flash Over and Insulation Breakdown. A flash over may be the result of great roughness of the commutator, or it may result from sudden rushes of current due to other causes such as bad contact with the working conductor (brought about by sleet and snow on third rail or trolley), a momentary interruption and reestablishment of the circuit through the motor, or a surge set up in the supply by a remote disturbance such as a short circuit or the flashing over of another motor. Thus the flashing over of one motor may cause other motors on the same line to flash over. A flash over may be due to a combination of high counter electromotive force and consequent weak field caused by abnormally high speed, a combination which may be produced, for instance, in running on a long down grade with power on. A flash over may also take place because of a conducting path offered by the particles of copper and carbon resulting from the grinding process noted in the paragraph preceding. This dust also works into the insulation, thus reducing its efficiency and in some cases preparing a path for a breakdown. This process of insulation breakdown is most liable to take place in the higher voltage motors.

Commutating-poles. In the railway motor the commutating-pole (also called the interpole) is a small pole piece placed between the main poles with its windings in series with the armature. The total weight of copper in a commutating-pole motor is nearly the same as that in the non-commutating-pole motor because the introduction of commutating-poles makes possible a reduction in the number of field turns. The function of the interpole is to improve commutation at all loads and voltages on the motor. It accomplishes its purpose by providing a field which when swept through by the armature coil short-circuited by the brush will produce a complete current reversal in that armature coil so that there will be no spark when contact is broken between the commutator bar and the brush which it is leaving. Incidentally the commutating-pole prevents or diminishes the possibility of flash overs by restricting rushes of current. The commutating-pole is permanently connected directly in series with the armature, and whenever, as for the purpose of changing the direction of rotation, the direction of the current to the armature is changed the direction of the current in the commutating-pole winding must be changed. The current in the commutating-pole winding varies with that in the armature, consequently, if the motor operates successfully at one load it will operate successfully at any other load up to the point of saturation of the commutating-pole. The commutating-pole operates most satisfactorily at below saturation. At loads considerably above that whose current in the commutating-pole winding causes saturation of the commutating-pole the influence of the commutating-pole is annulled by the flux due to the current in the armature and with a still further increase of load commutation would be worse than with no commutating-pole.

Advantages of commutating-pole railway motors as compared with non-commutating-pole railway motors are briefly set forth by

Mr. E. H. Anderson, A.I.E.E., 1907, as follows: (1) Sparkless commutation even on heavy overloads (of particular advantage where many stops make rapid acceleration desirable); (2) flashing at commutator largely reduced and probably eliminated; (3) less wear on commutator; (4) cleaner and safer motor because of reduced carbon and copper dust from brushes and commutator; (5) marked reduction in heating of commutator; (6) greater current density in brushes; (7) increased life of brushes; (8) increased efficiency and free running capacity because of lower core and commutator losses; (9) possibility of successfully using higher voltages; (10) greater facility in design of large motors, especially as regards commutation; (11) possibility of increasing service capacity of motors by blowing. To these may be added the possibility of speed control by field regulation because satisfactory field control of a series railway motor is made possible only by the commutating-pole.

The advantages of commutating-poles are of least importance with low-voltage and low power motors.

Relative to a railway motor with commutating poles, an article by Mr. Clarence Renshaw, Electric Journal, 1907, says, "A properly designed motor of this type should run practically sparklessly from a load so light as to give treble the normal speed up to loads as heavy as double its ordinary 1-hour rating. It should permit high voltages to be thrown on it, either at standstill or when running at high speeds, and its stability should be so great that it will commutate, without appreciable sparking, rushes of current which in the ordinary motor would invariably cause flashing. This great freedom from sparking makes the interpole motor especially well adapted for high-voltage service."

In the Electric Journal, 1910, Mr. J. L. Davis states that the interpoles on the locomotives (4000-h.p. locomotives with field control and interpoles) for tunnel service on the Pennsylvania Railroad develop 2500 h.p. with the weakest field without appreciable sparking and that when running at 70 miles per hour on 725 volts, the highest speed notch and the weakest field, gaps in the third rail are crossed without any spitting at the brushes. He also states that a 200-h.p. commutating-pole motor running on 800 or 900 volts at very high speeds will take a current rush of two and one-half times full load without flashing. In a discussion, Mr. W. B. Potter, A.I.E.E., 1907, states, relative to motors suitable for operation on higher voltage direct current (and 600 volts), ". . . . . a motor having commutating-poles and designed for operation on 600 volts can be run at full load on 1000 volts so far as commutation is concerned, and further, such a motor, when the current is momentarily interrupted, or there is a momentary rise in voltage, will not flash over, as sometimes happens with motors not having commutating-poles. A commutating-pole motor designed for 1200 volts and operated at that potential would be superior to the ordinary 600-volt motor, both with respect to commutation and liability to flash over." Interpoles to prevent flashing are not so necessary in motors of low rating as they are in motors of high power rating because of the greater choking effect due to the greater number of turns on the field of the smaller motor which restricts the flow of current. In the Electric Journal, 1910, Mr. J. L. Davis says that on a 40-h.p. motor, running at high speed at one-third full-load current, the breaking of the circuit and a quick reapplication of full voltage will cause a rush of not more than full-load current through the motor, and in a 200-h.p. motor running on 750 volts at one-third full-load current and subjected to similar treatment a rush of current of 150 per cent. overload current may result.

Advantages of Commutating-poles on 500- and 550- Volt Motors in Practice. To question 84, Question Box, A.E.R.E.A., 1911: "What are the advantages obtained, if any, by using interpole motors for strictly city service; 500 to 550 volts?" Replies as follows were received from nine companies: One company reported having operated twenty-three 4-motor equipments for about 10 months with no flash overs, while flash overs on non-interpole motors were not uncommon; one stated that for heavy service the use of interpole motors saves one-half maintenance expense; one, that there is an increased overload capacity for the same sized motor; one stated the belief that up to and including 40-h.p. motors it is not advantageous to use interpole motors for city service, where the average voltage is from 500 to 550 volts; two reported no flash over troubles; two reported less flash over troubles; two reported longer brush life; one reported little wear on the commutator; one reported reduction of motor troubles due to carbonization; one reported less brush holder trouble; one each reported "none" and "very few."

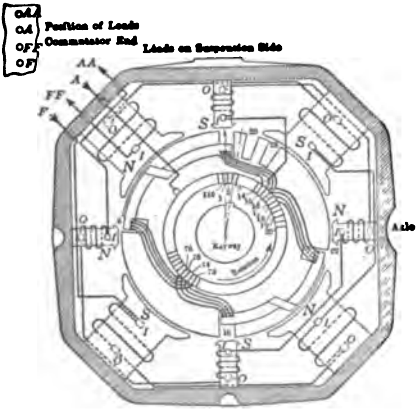


FIG. 67.—GE-201 motor.

Wiring Diagrams of Commutating-pole Motors. Figs. 67 to 71, inclusive, show the direction of rotation, throw of the leads and the method of bringing out the leads on typical commutating-pole motors.

Armature Repairs. The following is from the report of the 1907 Committee on Electrical Equipment, A.E.R.E.A. "For insulation of armature coils wound with round wire and where the ultimate temperature rise is less than 65 deg. C., cotton-covered and varnished cambric insulation is sufficient. Where ultimate temperature rise is 65 deg. to 100 deg. C., asbestos covering for the wiring is necessary. In the use of asbestos material your committee would call attention to the vital importance of impregnation with moisture-repelling varnish. The asbestos should be considered as a fireproof material and a good spacer rather than a good insulator. Armature coils and especially those wound with asbestos-covered wire must be held rigidly in place in the armature core to exclude all movement or vibration in the slot or at the ends. By some roads it is considered good practice to impregnate an armature after it is wound by heating and revolving it in an impregnating bath. The advantage of this method is improved insulation and rigidity of windings in the core. The disadvantage is the difficulty of raising a coil should it be necessary to patch up an individual coil. Experiment is suggested with the use of all-fireproof insulation of armature coils; that is, asbestos-covered wire; spacing and wrapping with mica and wrapping with asbestos tape. It is suggested that this process may give longer life even under moderate temperatures than the cotton-covered, oiled-cambric wrapped coils." (A.E.R.E.A. Miscellaneous Practice.) Where the original equipment was bar wound, it is recommended that insulation be mica, partially, if not wholly; where bars are to be replaced it is preferable to replace with bars similar to the original, that is, with insulation of mica. However, should it be necessary to repair at short notice and no mica-insulated bars are at hand, a varnished cambric-insulated bar is recommended, appreciating

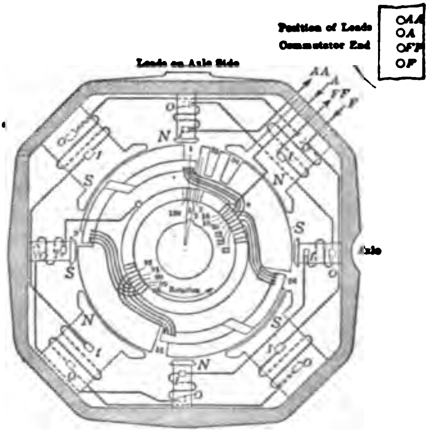


FIG. 68.—GE-203 motor.

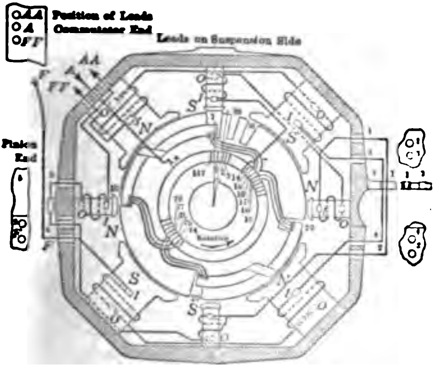


FIG. 69.—GE-200A motor.

that the life is not as great as mica and shorter as the working temperature is higher.

Tests of Rewound Armatures. The following list gives the tests in the order of their application to completely rewound armatures by the Chicago Rys. Co.: (1) Breakdown test between commutator and sleeve as assembled off the machine; (2) breakdown test between the commutator and sleeve, with commutator on the shaft; (3) bar to bar test on commutator; (4) after coils are in slots, with lower leads connected to commutator; breakdown test, commutator to ground; (5) after coils are in slots, with lower leads connected to commutator; breakdown test between adjacent leads; (6) after coils are entirely connected in and before soldering; breakdown test, commutator to ground; (7) after coils are entirely connected in and before soldering; make short circuit tests on armature coils; (8) after banding, short circuit and open circuit tests on armature coils; (9) after banding, breakdown test to ground.

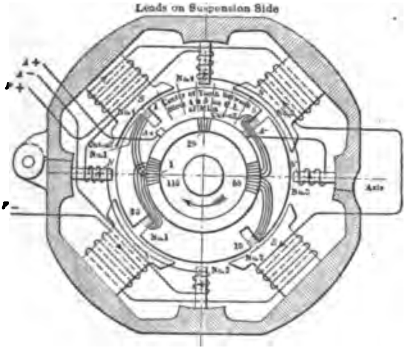


Fig. 70.—WE&M-306 motor.

Locating Short Circuits in Armatures by Direct Application of Alternating Current. The following method described by Mr. Leonard Work, Electric Journal, 1910, is stated by him to be rapid and thorough (Fig. 72). Alternating current is applied to the commutator through contacts separated by an amount equal to the correct brush separation for ordinary operation of the motor. While this continues, connection is made and broken between any pair of adjacent bars as at *A* on the side of the commutator opposite the points where the alternating current is applied.

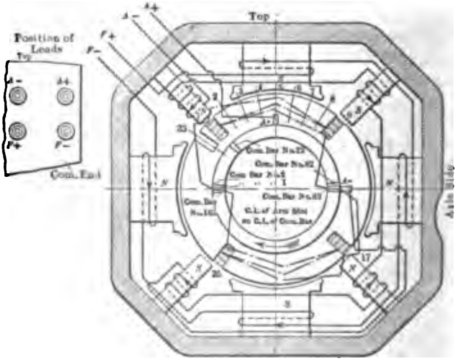


Fig. 71.—WE&M-321 motor.

If on such making and breaking there is a small spark, there is no short circuit between these adjacent bars. If there is no spark, a short circuit exists between these two bars. The points at which the alternating current is applied to the armature are advanced around the armature and the test is continued between each pair of adjacent commutator bars. In making this test, approximately full-load current should be applied. The test is made with the armature removed from the motor frame.

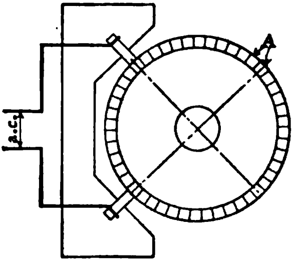


Fig. 72.—Test of armature for short circuit.

Armature Test by Full-load Current. In the shops of the Brooklyn Rapid Transit Company armatures removed from the motor frames are tested for poor soldering, defective leads and short circuits in commutator or armature winding by passing full-load current through the armature by way of a pair of brushes set in the same relative positions as for actual operation. The current flowing through the armature and the voltage drop between adjacent commutator bars are measured. Poorly soldered connections and abraded leads are burned off by the current. The testing outfit consists of a rheostatic controller and a set of car resistances arranged to give any desired current from 8 to 300 amperes, an armature circuit breaker and switch. Fig. 73 gives a wiring diagram for the outfit.

Insulation Test of Armature Coils. (A.E.R.E.A. Proposed Practice): Between windings and ground.

For roads using trolley:

New armatures	2500 volts, a.c., 5 seconds
Old armatures	1000 volts, a.c., 5 seconds

For roads using third rail where voltage fluctuations have to be taken into consideration:

New armatures	3000 volts, a.c., 5 seconds
Old or partly repaired armatures	1500 volts, a.c., 5 seconds

Between armature coils before windings are connected.

New armatures	220 volts, d.c., 5 seconds
Old armatures	110 volts, d.c., 5 seconds

The Boston Elevated Railway uses the following:

New armatures	1600 volts, a.c.
Old armatures	1000 volts, a.c.

Several momentary applications of this electromotive force are made in each case.

Equipment for Armature Insulation Testing. The Chicago City Railway Company uses a motor generator set consisting of a single-phase, 12-kw., 230-volt, 125-cycle generator excited by a 1.5-kw., 125-volt belted exciter and driven by a 550-volt, 1875-rev. per min. direct-current motor. The testing electromotive force

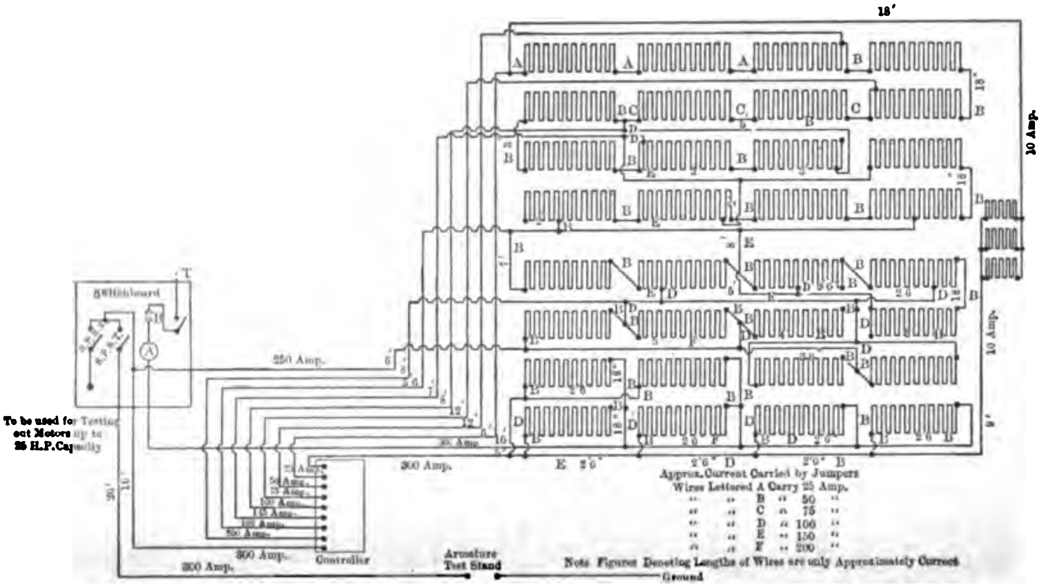


FIG. 73.—Arrangement for armature testing—Brooklyn.

is obtained by the use of a 5-kilovolt-ampere 6000-volt transformer arranged to give a voltage of from 200 to 6000 in twelve steps.

Locating Short Circuits and Open Circuits in Armature Coils by Yoke Transformer Test (Fig. 74). A "U" shaped two-pole laminated iron core having its pole pieces cut to embrace the armature as is done by the motor field pole pieces, and carrying an exciting coil about its yoke, is placed against the armature to be tested. When the coil on the yoke is excited by an alternating current, the resulting flux passes through the armature core and its windings and induces an electromotive force in the latter. The armature coils which are in a position to link with the greatest number of lines of magnetic force have induced in them the highest electromotive force and if one of these coils be short-circuited a heavy current will flow through it and this will be evidenced by heating of the coil, or by the noisy vibration of a soft iron test piece laid over the armature. Manifestations remain the same when the two adjacent commutator bars to which the terminals of a short-circuited coil are connected are short-circuited by having a piece of metal inserted between them and the testing current is momentarily applied. The test is continued around the armature by revolving it so that one coil at a time will come under the influence of the strongest field. The coils not found to be short-circuited are next tested for open circuit. This is done by short-circuiting adjacent commutator bars, pair at a time, and applying the test for short circuit to the corresponding coil. An indication of a short circuit when this is done proves the absence of an open circuit in the coil. In testing for open circuit the vibration test should be used and the current should not be kept on long enough to damage the coil under test. The alternating electromotive force applied to the testing coil used by the Boston Elevated Ry. Co. is from 700 to 750 volts. The Pittsburgh Railways Co. excites the testing coil by connecting it to a convenient lamp socket. For ease in handling, the latter company has bolted the testing yoke to the top cross-piece of a two-wheeled warehouse truck arranged so the truck frame will stand vertically when tipped up. This arrangement permits the testing yoke to be quickly moved to the armatures which are mounted on wooden horses of such height that the armature core center shall be even with the center of the testing yoke when the truck is tipped up.

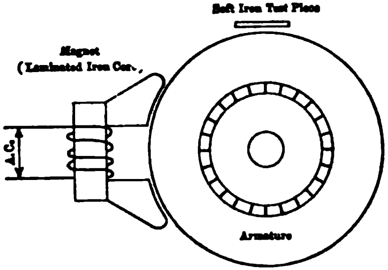


Fig. 74.—Yoke transformer test for armatures.

Bar to Bar Armature Test. Method of locating open circuits, short circuits and grounds in a closed coil armature (Fig. 75).

In the following discussion, "meter" refers to the instrument with which the readings are taken; this may be a galvanometer, a low-reading voltmeter, or a telephone receiver. If a telephone receiver is used, "deflection" refers to the click of the telephone receiver when the circuit is made or broken through it. Two or three cells of battery will be sufficient for ordinary work. The battery is first connected across opposite commutator bars. If the deflections are the same when the meter is connected to each pair of adjacent commutator bars, then there are no open circuits, short circuits nor leads interchanged.

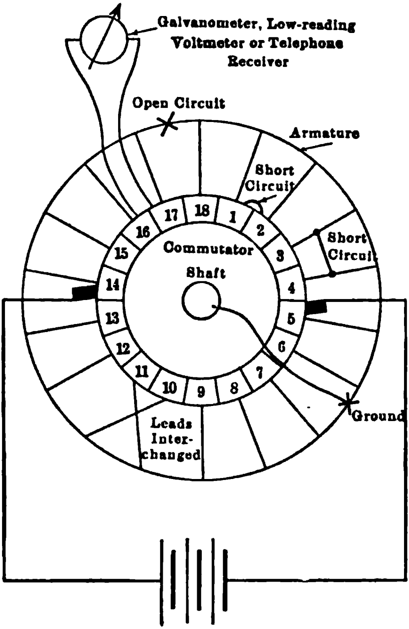


Fig. 75.—Bar to bar armature test.

Open Circuit. The battery is connected to two points on the commutator (these points need not be diametrically opposite each other) and the meter is connected across each pair of adjacent commutator bars in turn. Zero deflection indicates an open circuit. When there is but one open circuit on one side between the battery contact points there will be a great deflection when the meter is connected across the adjacent commutator bars (as 17 and 18) which lie on either side of the open circuit. When an open circuit is located it should be closed temporarily by a drop of solder between the two adjacent commutator bars between which the break occurs. If other open circuits exist they may be located by shifting the battery contacts to other points and repeating the above process.

Short Circuit. When the meter is connected between two adjacent bars such as 1–2 and 3–4, between which there is a short circuit, there will be a very slight deflection.

Leads Interchanged. If as between 10 and 11 the deflection is reversed, the armature leads connected to bars 10 and 11 are interchanged from their correct position.

Ground. The battery is connected to two points of the commutator, approximately opposite each other, one meter terminal is connected to the armature shaft, and the other is drawn completely around the commutator. If there is only one ground there will be found two balancing points, or points giving the least deflection. Next, the two battery contacts are to be shifted a few bars one way or the other. When this is done one balancing point will be found at the same bar as before, thus showing the approximate location of the ground. The other balancing point will move with each change of battery connection if but one ground exists.

Mummified Field Coils. The use of mummified strap-wound field coils with asbestos insulation has become practically universal, and round wire is used only on the smallest sizes of motors where the section is so small that there is no gain by the use of flat copper ribbon. The field coils are wound with strip copper and insulated between turns with strip asbestos and between decks with flexible mica. After being wound, the field coils are compounded in the vacuum treatment, which fills the coils thoroughly. After being cleaned of compound, the coils are wrapped with varnished cambric and tape and the coil is submerged in insulation varnish. Thus insulated with heat-proof insulation in the interior, the coil is able to stand higher temperature than earlier types. The external insulation makes the coil practically waterproof. This construction makes a solid coil which when used with spring backing is held perfectly tight. The purpose of the spring back is to prevent the chafing of insulation, breaking of leads and grounding of the coil. The following is A.E.R.E.A. Proposed Practice: "For fields where temperature rise will not exceed 65 deg. that the wire be cotton-covered and coil impregnated with solid compound and wrapped with varnished cambric, further wrapped with heavy webbing and dipped in varnish. For fields where temperature rise is 65 deg. to 100 deg. C., that the wire be asbestos-covered, and coil impregnated with solid compound and wrapped with asbestos tape, the asbestos tape to be also thoroughly impregnated. The above recommendation for temperatures between 65 deg. and 100 deg. applies to strap-wound fields, as well as those of round wire."

Insulation Test for Field Coils. (A.E.R.E.A. Proposed Practice.) For roads using trolley:

New fields	2500 volts, a.c., 5 seconds
Old or partially repaired	1000 volts, a.c., 5 seconds

For roads using third rail where voltage fluctuations have to be taken into consideration:

New fields	3000 volts, a.c., 5 seconds
Old or partially repaired	1500 volts, a.c., 5 seconds

Field Coil Test by Full-load Current. Full-load current is applied to the field coil. Temperature and voltage drop across the coil are observed and compared with those for a field coil known to be good.

Field Coil Test by Transformer. During this test the field coil becomes the secondary winding of a transformer (Fig. 76). The field coil is placed on the laminated iron core and the yoke placed to complete the magnetic circuit. Alternating current is then applied to the primary. The primary voltage applied and the ratio of the number of turns in the coil under test to the number of turns in the primary coil must not be such that a voltage dangerous to the operator or insulation will be induced. If there is no short circuit in the field coil the current taken by the primary at any

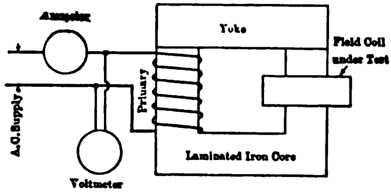


FIG. 76.—Transformer test for field coils.

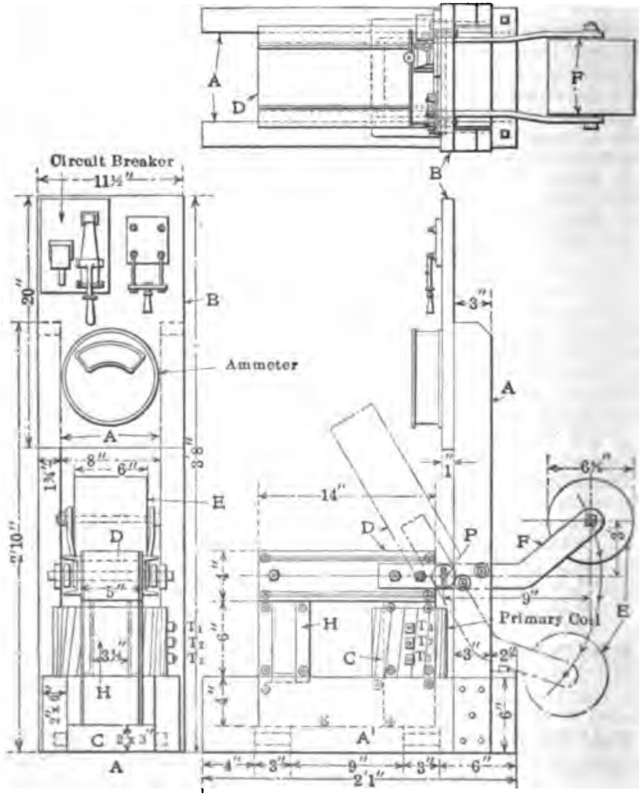


FIG. 77.—Arrangement for testing field coils—Brooklyn.

applied voltage will be the same as without the field coil in place but with the yoke in place. A short circuit in the field coil is evidenced by a considerable current in the primary, and if the applied voltage be of sufficient value the field coil will become appreciably heated by the induced current flowing within itself. The terminals of a field coil found to contain no short circuit are then connected together and the test for short circuit is repeated on this field coil. If there is no evidence of short circuit when this is done then there is an open circuit within the coil. If, however, the test indicates a short circuit, this field coil contains no open circuit. Fig. 77 from the Electric Railway Journal, 1913, shows the construction of a field-testing transformer used in the shops of the Brooklyn Rapid Transit Company. The framework *A* is made of wood. *B* is a slate panel 20 × 11½ × 1 in., on which the circuit-breaker, ammeter and switch are mounted. *C*, *H* and *D*, which comprise the magnetic circuit, are made of several thicknesses of 1/32-in. wrought iron dipped in shellac. After the shellac was dried, the laminations were placed between the two ¼-in. side pieces and riveted together. The primary coil is made up of eighty-one turns of No. 5 B. & S. double cotton-covered wire with twenty-seven turns between T-1 and T-2 and eighty-one turns between T-1 and T-3. *E* is a cast-iron counter-weight 6⅝ in. in diameter and 6 in. wide which assists in raising *D* and also in keeping it in the upper position while a field coil is being placed in position for testing or while one is being removed. The arms, *F*, made of ½ × 2 in. flat iron, bolted to *D*, have the counterweight attached at the other end and are free to turn on a pin. *D* and counterweight *E* thus revolve on the same pin, which is supported by two brackets, one on each of the upright members of the wooden frame.

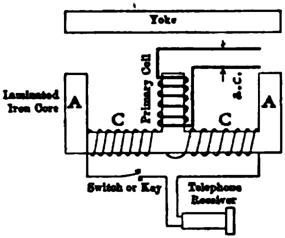


FIG. 78.—Transformer for testing field coils.

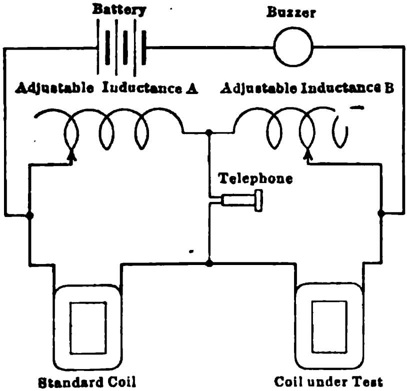


FIG. 79.—Inductance balance for testing field coils.

Fig. 78 shows another arrangement for making the transformer test of field coils. *C C* are two similar coils, so connected that the voltage induced in one shall oppose that induced in the other. The field coil to be tested is placed on one of the legs *A* (the yoke not being used in this case) and an alternating current is applied to the primary coil. If the field coil under test contains no short circuit, the sound in the telephone receiver will be very faint. If, however, there is a short circuit in the field coil, this will unbalance the fluxes through *C C* and the sound in the telephone receiver will be loud. The terminals of a field coil found to contain no short circuit are then connected together and the test for short circuit is repeated. A loud sound in the telephone receiver now indicates that there is no open circuit in the field coil. A faint sound indicates that there is an open circuit in the field coil. If it is desired, this apparatus, together with the yoke but without the telephone receiver, may be used to test field coils in the manner outlined in the preceding paragraph.

Field Coil Test by Inductance Balance (Fig. 79). Instead of the battery and buzzer indicated, a low-voltage alternating current may be used. A standard coil known to be faultless and similar to what the coil under test should be if perfect, also the coil to be tested are connected as shown. The adjustable inductances *A* and *B* are then adjusted to give a balance which is indicated by the faintest sound in the telephone receiver. If *A* and *B* are then practically alike, the coil under test is without short circuit or open circuit. If, however, *B* is less than *A* there is a short circuit in the coil under test.

Insulating Materials for Railway Shop Use

(A.E.R.E.A. Miscellaneous Methods and Practices)

Definitions. *Air Drying Varnishes.* Linseed oil or other drying oils, with such driers and treatment as to dry quickly without necessity for baking.

Baking Varnishes. Linseed oil or other drying oils, with gums and driers. Requires baking.

Spirit Varnishes. Animal or vegetable gums, shellac, copal, etc., dissolved in alcohol, amyl acetate, benzine, etc.

Insulating Paints. Solutions of asphalt, and mineral gums in carbon bisulphide, naphtha, etc.

Impregnating Compounds. Petroleum asphalt, melting point 105 to 115 deg. C., used for impregnating motor fields, etc. Paraffine and linseed oil are each used as impregnating material for special purposes as described below.

Air drying varnish should be composed of linseed oil or other drying oils sufficiently treated and with proper amount of dryers so that varnish will dry in 2 or 3 hours, leaving a smooth, flexible surface. Baking not required. Should be both oil and moisture proof. Should not crack, soften or become tacky at 100 deg. C.

Baking Varnish. Composed of high-grade linseed oil, with some gums and dryers. Baking varnish should not be used except baked at 100 to 110 deg. C. for 10 or 12 hours. Characteristics: high melting point, flexibility, smooth, glossy surface, good filler, high insulating qualities, oil and moisture proof.

Spirit varnishes are composed of animal and vegetable gums, such as shellac, copal, etc., dissolved in spirits. Characteristics: oil proof but not moisture proof; good stickers and binders, but not necessarily good insulators. In general they soften at 100 deg. C.

NOTE: On string band or webbing covering mica at the outer end of the commutator it is recommended that no varnish be used that will soften at a temperature of 100 deg. C.

Insulating Paints. These are solutions of asphalt or mineral gum in naphtha or other solvents. Characteristics are moisture proof but not oil proof, lacking in toughness, good as a sticker and paint, but not high in insulating qualities.

Impregnating Compounds. *Asphalt Compounds.* Composed of asphalt. Characteristics: Different asphalts have widely different melting points. The asphalt to be used is one in which the melting point is above the operating temperature, preferably 110 deg. C. At ordinary temperature should be somewhat pliable, but should not flow. At melting point should flow freely. Is moisture proof, but not oil proof. Good as a filler, and has fair insulating qualities. Asphalt should be practically free from volatile matter. In order to get a good penetrating asphalt the committee recommends that the asphalt shall not contain more than 5 per cent. of constituents insoluble in carbon bisulphide (CS_2).

Paraffine is a mineral gum of a low melting point, suitable for impregnating wood for outside or low temperature work. Is not suitable for use in railway apparatus where working temperature is over 50 to 60 deg. C.

Linseed oil is excellent for filling wood parts of railway apparatus. The parts should be boiled in raw linseed oil until filled and then baked to oxidize same, the wood to be finished with either an air drying or baking varnish. Wood treated in this manner is excellent for outdoor work, exposed to climatic conditions. Linseed oil hardens under temperature, does not melt, is moisture and oil proof and is flexible and strong.

Tests for Insulating Materials. The following simple tests are recommended for the various substances: Without an elaborate testing laboratory, it will be impossible to find the exact values of tests on the various insulating compounds, but these tests can be made with little or no apparatus and serve as very good general tests of the material.

Asphalt.. The chief consideration in connection with asphalt is the melting point. Asphalt can be obtained from a low to a very high melting point. Some asphalts contain as high as 30 per cent. of inorganic matter. In order to determine how much inorganic matter, a certain definite amount of the asphalt can be melted and burned away in an ordinary crucible or gas flame. The presence of sulphur and the degree may be determined by melting the asphalt and allowing a bright sheet of copper to remain in the melted asphalt for 2 or 3 days. The tarnishing of the bright copper will indicate the presence and quantity of sulphur.

Linseed Oil. Linseed oil may be heated up to the boiling point, and if there be any foaming and spluttering as it begins to boil, it indicates presence of water in the oil. Linseed oil may have a sediment usually known as "foots." The relative amount may be approximately determined by allowing a sample of the oil to stand in a test tube for about 24 hours and noting the amount of sediment deposited. Regular boiled oil has a specific gravity of 0.945 or higher, whereas the ordinary boiled oil which has been produced by pouring into the bunghole a certain amount of drier, has a specific gravity but little higher than raw linseed oil, this specific gravity being 0.931. Acids are used during the process of refinement. In order to test the amount of acids, it would be well to immerse a bright copper strip in the oil for several days.

Japans and Varnishes. These should be tested at a temperature which is ordinarily used in service. After the coating has thoroughly dried in the air or by baking, according to which treatment the material is designed, the flexibility of the coat may be determined. It would be well to test with a bright copper strip for acids.

Shellac. Shellac contains more or less rosin. The determination of this requires elaborate analysis. The quality of the shellac, however, may be determined by painting on bright tin, and by making comparisons with other shellacs, the flexibility may be determined. A very flexible shellac has little or no rosin. The presence of rosin makes it brittle. It would be well to test with a bright copper strip for acids.

Paraffine. The chief difficulty in paraffine is water and sulphuric acid from the refining processes. The amount of water can be determined by heating; foaming and sputtering on reaching the boiling point indicating the presence of water. Sulphuric acid can be detected by the immersion of a bright copper strip, or by mixing some of the paraffine with boiling water and then pouring off the water and testing with litmus paper.

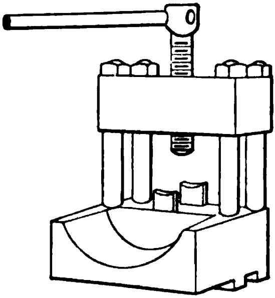


FIG. 80.—Screw press for straightening armature shafts.

Straightening Armature Shafts. *Screw Press.* The following description of a screw press for straightening armature shafts is from the 1908 Committee on Maintenance and Inspection, A.E.R.E.A. (Fig. 80). The screw is 2½ in. in diameter, the columns 2-in. rod, the top and bed block cast iron, and the bar 1¼-in. octagonal steel 8 ft. long. The bent portion of the shaft is laid on the V-blocks and the screw pressure applied between them. Where the shaft is bent close to or inside the laminated core, the core is carried on a piece of leather on the concave part of the bed block, and the shaft supported by one V-block. For convenience the press is operated on the bed of a large engine lathe. The armature is removed from the lathe centers when pressure is applied, after which it is placed on centers to try shaft for straightness.

Hot Straightening. The following description and account is from practice in the shops of the Boston Elevated Railway, Electric Railway Journal, 1910. The shaft to be straightened is heated by a hollow cast-iron collar inside of which a mixture of gas and air is burned. When assembled, the collar is 14 in. in diameter, 7.5 in. long and has a central longitudinal hole 5 in. in diameter through which the shaft extends in the process of heating. The collar is made in two parts which are latched together; each half is a cored casting having walls ½ in. thick and its core holes plugged with pipe plugs. The inside of each half cylinder is drilled with 1/32-in. holes used as flame apertures, of which there are 96 in the complete collar. Each half is supplied with gas and air through ½-in. pipes. When used the collar is set on a metal plate across the bed of a lathe and the shaft to be straightened is placed inside the collar and held in position between special lathe centers until it is heated to a red heat. Shafts were formerly bent in cold condition by one man and a helper, the work requiring from 2 to 3 hours, according to the nature of the distortion. By the heating process it was done by one man in one-half to three-quarters of an hour. and the shaft was left in better condition than when bent cold, Formerly trouble was experienced from the crystallization and subsequent breakage of cold-bent shafts. The heating was not detrimental to the wearing value of the metal and the resulting strength improved the service materially.

Railway Motor Gears and Pinions

Pitch. The diametrical pitch (number of teeth per inch of diameter of pitch circle) commonly used is 2.5; 3 is also used, but for motors of not greater than 75 rated h.p. Larger teeth are used on locomotives.

Taper of Pinion Bore. A taper for bore of pinion in the proportion of 1.25 in. in diameter to 1 ft. in length was adopted as standard by the Am. El. Ry. Eng. Assn., 1911.

Cast Steel Split Gears. The halves of eight bolt gears are fastened together by four bolts on each side of the hub, two of each four being placed beside each other near the hub, and the other two as near the rim as possible. There are two methods of bolting the halves of four bolt gears together. One method is to place one bolt on each side of the hub and the other two out near the rim. Another method is to place two bolts on each side of the hub, side by side between hub and rim. A complaint in connection with split gears is that the bolts are often stretched beyond their elastic limit.

Cast Steel Solid Gears. Generally speaking, solid gears can be made stronger and lighter than split gears, moreover, they require no key seating in the axle.

Diameter Allowance and Pressure Required to Fit Solid Gears. From a paper by Mr. T. W. Williams before the Street Railway Association of the State of New York, 1910: "An allowance of 0.001 in. for every inch of axle diameter should require from 40 to 60 tons to force the gear in place, and such a fit is ample to prevent the gear from slipping."

Tooth Pressure. In a paper on the design of the electric locomotive by Messrs. N. W. Storer and G. M. Eaton, A.I.E.E., 1910, it is stated that experience indicates a pressure of 1000 lb. per inch width of gear face as a perfectly practicable value for continuous rating of large gears, and that with special steel pinions and high-grade gears it is probably safe to exceed this figure. In the St. Clair Tunnel locomotives the pressure is carried on a single gear having a 6-in. width of face on the gears. The life of the pinions is 40,000 to 50,000 miles. With the normal loads at which the locomotive operates on up grade the pressure is from 1500 to 2000 lb. per inch width of face on the gears.

Factors Essential to Durability of Gears and Pinions. The most important factors conducive to long life of gears are: (1) Proper steel properly treated; (2) proper alinement; (3) proper lubrication; (4) tight gear cases.

Specifications for Gears and Pinions for Motors of 50 h.p. and Over. The following specifications for gears and pinions were suggested by the 1908 committee on maintenance and inspection of the Am. El. Ry. Eng. Assn.: Castings to be of open-hearth steel or other approved process. They must be free from shrinkage cracks and spongy portions. The design of gear must be such as to minimize shrinkage strains. The unfinished surfaces must be reasonably smooth and free from sand and scale. The finished surface of the teeth and the finished rim below teeth should be reasonably free from sand, gas or blow holes and must not fall below specifications as given below. No tooth or finished surface between teeth shall have sand, gas or blow holes which will reduce the strength of the tooth more than 10 per cent. on motors of 100 h.p. or under, or more than 7½ per cent. for motors of 100 h.p. or over. When sand holes are detected in a tooth, a chisel with 3/16-in. cutting edge should be used to determine the depth and extent, as frequently a hole which appears on the surface to be very small will be found to contain a great deal of sand. In the case of gas or blow holes, the chisel should be used to open them up if possible and then a small piece of flexible wire inserted to find the extent of the cavity to which they lead. If this cavity enlarges under a tooth or between teeth in such a manner as to affect the strength of the tooth to the extent mentioned above, the gear will be rejected. The other portions of the gear must not contain gas, shrinkage or sand holes to affect the strength of these portions more than 10 per cent. It is the practice of some manufacturers of gears to fill gas or shrinkage holes with a mixture or compound which greatly resembles the metal itself. This does not add to the strength of the tooth or gear, and prevents the above inspection being made. The committee, therefore, recommends that any gears so treated be rejected. The thickness of the rim between the teeth, measured at a point 3/8 in. from the finished edge of rim, must not be less than ½ in. for 3-pitch teeth, and 5/8 in. for 2½-pitch teeth. For split gears, the aggregate cross-sectional area of the bolts or studs holding halves together, preferably, should not be less than 4.8 sq. in., measured in the body of the bolt, for the lightest gear, and increase for the heavier gears consistently with other dimensions. All nuts must be positively locked by means other than a spring lock washer. The thickness of the teeth, compared one with another, must not vary more than 0.01 in. and thickness at correct pitch line must not exceed the correct thickness and must not run below correct thickness by more than 0.010 in. Pitch line must be concentric with bore. On solid gears with axles up to 6 in. in diameter, the bore must not vary in diameter more than 0.001 in. over and 0.002 in. under given dimensions. For split gears the bore must not be greater than given dimensions. All gears should be stamped with the name of manufacturer and date of manufacture in a place not subject to wear and where same can be seen without removal of gear. The steel in gears must not contain more than 0.06 per cent. sulphur or more than 0.06 per cent. phosphorus, and must have the following physical properties: Tensile or ultimate strength not less than 60,000 lb. per square inch; elastic limit or yield point not less than 27,000 lb. per square inch; elongation in 2 in. not less than 15 per cent. per square inch; contraction of area not less than 20 per cent. per square inch. The bolts used for split gears should have the following physical properties: Ultimate strength, 60,000 lb. per square inch; elastic limit, 35,000 lb. per square inch. The committee recommends the serious consideration of solid gears and their adoption wherever practicable.

Specifications for Railway Motor Pinions, for Motors of 50 h.p. and Over. Finished surface of teeth must be absolutely free from flaws of any kind. The thickness of the teeth, compared one with another, must not vary more than 0.010 in., and thickness at correct pitch line must not exceed the correct thickness and must not run below correct thickness by more than 0.010 in. Pitch line must be concentric with bore. The bore must not vary in diameter more than 0.001 in. under and 0.001 in. over given dimension. The name of the manufacturer and date of manufacture should be stamped on the pinion in a place not subject to wear; preferably on the end of pinion on which the diameter of bore is smallest. Their physical characteristics should be as follows: Tensile strength, 110,000 lb. per square inch (minimum); elastic limit, 70,000 lb. per square inch (minimum); elongation in 2 in., 15 per cent.; reduction of area, 20 per cent.

Classification of Gears and Pinions. The following classification of gears and pinions according to material and treatment was given by the 1912 committee report on equipment Am. El. Ry. Eng. Assn.:

Gears	Cast steel	Plain	
		Alloy	
		Heat treated	Quenched Surface treated
	Forged or Rolled steel	Plain	
		Alloy	
		Heat treated	Quenched Surface treated
Pinions,	Forged	Plain	
		Alloy	
		Heat treated	Quenched Surface treated

Physical Characteristics and Chemical Composition of Gears and Pinions. The following tables of approximate values were constructed on the same report (hardness as given is from Brinnel Hardness Gage):

PHYSICAL CHARACTERISTICS, GEARS

Material	Tensile strength, pounds	Elastic limit, pounds	Reduction in area, per cent.	Elongation, per cent.	Hardness
Cast steel	60,000	25,000	20	18	140
Cast steel (tempered in oil).	75,000	45,000	40	24	200
Forged steel	85,000	55,000	35	22	165
Hard steel alloy	95,000	55,000	30	30	....

PHYSICAL CHARACTERISTICS, PINIONS

Material	Tensile strength, pounds	Elastic limit, pounds	Reduction in area, per cent.	Elongation. per cent.	Hardness
Forged, (low carbon)	55,000	25,000	35	50	150
Plain forged (high carbon).	85,000	50,000	40	20	200
Heat-treated forged (low carbon).	100,000	55,000	40	18	230
Heat-treated forged (high carbon).	115,000	82,000	33	15	300
Special alloy	95,000	55,000	30	30	....

CHEMICAL COMPOSITION OF THE ABOVE GEARS AND PINIONS

Piece	Carbon, per cent.	Manganese, per cent.	Phosphorus, per cent.	Sulphur, per cent.
Cast steel gear	0.40	0.60	0.04 (max.)	0.04 (max.)
Forged steel gear	0.40	0.60	0.04 (max.)	0.04 (max.)
Forged steel pinion (low carbon).	0.40	0.60	0.04 (max.)	0.04 (max.)
Forged steel pinion (high carbon).	0.60	0.75	0.04 (max.)	0.04 (max.)
Special alloy pinion	0.30	0.13	0.04	0.04

Approximate Life of Gears and Pinions. The following information is from a paper by Mr. T. W. Williams at a meeting of the Street Railway Association of the State of New York. Data from gears and pinions (2.5 pitch) on 100-h.p. motors on two cars identical as to weight, motor capacity, running schedule and route. The life was estimated by subtracting the amount of wear on the pitch circle of the teeth after running 50,000 miles from the original thickness and then estimating how many more car miles the teeth could run before 0.1 in. had been worn from each face of the teeth, on the basis that the wear would be constant throughout their life. The pitch of all the gears was 2.5.

Description	Life of pinion, miles	Life of gear, miles
Untreated high carbon pinion running with cast steel gear.	70,000	220,000
Heat-treated high carbon pinion running with cast steel gear.	100,000	240,000
Heat-treated high carbon pinion running with heat-treated high carbon gear.	250,000	750,000
Case-hardened pinion running with case-hardened gear.	200,000	650,000

The following from the same source is from tests of pinions under severe service conditions with a view to determining the relative merits of alloy steels, both treated and untreated, also heat-treated carbon steel. The pinions were of 2.5 pitch and 14.5 deg. angle. ("No. 1" and "No. 2" refer to the companies furnishing the steel.)

Untreated Chrome Nickel Steel, No. 1, 4 Pinions

One broken after	33,300 miles
One worn out after	84,800 miles
One broken from outside causes	85,600 miles
One, record lost.	

Chrome Nickel Heat-treated Steel, No. 1, 4 Pinions

One broken after	26,000 miles
One broken after	82,000 miles
Two, record lost.	

Chrome Nickel, No. 2, 4 Pinions

None broken	
Two worn out after an average of	98,500 miles
Two broken from outside causes after average of.	49,000 miles

Chrome Nickel Heat Steel, Untreated, 4 Pinions

One broken after	48,500 miles
One worn out after	33,000 miles
One removed due to change in gearing after	117,000 miles
One, record lost.	

Chrome Tungsten Nickel Steel, Untreated, 4 Pinions

None broken	
Two broken from outside causes after an average of	82,000 miles
One removed due to change in gearing after	119,000 miles
One, record lost.	

Carbon Heat-treated Steel, 10 Pinions

None broken, none worn out.	
Three broken from outside causes after an average of	73,800 miles
Five removed due to change in gearing after an average of approximately	115,000 miles
Two, record lost.	

The above tests indicate the advisability of using high-grade heat-treated steel or case-hardened steel for gears and pinions used with railway motors up to 75 h.p. capacity, while heat-treated carbon steel alone is best suited for gears and pinions which are subjected to higher tooth stresses by motors of larger capacity; for not only will the breakage of the teeth be reduced to a minimum, but the cost of the gearing per mile run will be considerably lower, notwithstanding the relatively high price paid for it.

"Columbus Shop Notes," Electric Railway Journal, 1912, gives as an average, figured from results with 440 cars in 1911:

GE grade D gear	176,201 miles
GE grade D pinion	127,451 miles

Necessity of High Quality of Pinion Material for Large Motors. The following statement was taken from the report of the 1912 Committee on Electrical Equipment, Am. El. Ry. Eng. Assn.: "Your committee would call your attention to the higher duty required of pinion material on the larger sizes of motors, as, for instance, a 40-h.p. motor pinion has a 5-in. face while a 200-h.p.

motor pinion has but 5.25 in. face. It is, therefore, of vital importance that consideration be given to pinion material being of quality suitable for the higher duty."

Material and Wear of Gears and Pinions. The following is an extract from the report of the 1910 Committee on Equipment, Am. El. Ry. Eng. Assn.:

"Your committee . . . would suggest that careful consideration be given to the matter of gear vibration, as it is evident from experiments made by one of the large manufacturing companies that this is responsible to a large degree for many failures such as broken armature leads, broken gear bolts, gear and motor cases, as well as broken armature shafts and axles. It would seem, therefore, advisable to establish limit of gear wear with reference to the elimination of gear vibration rather than with reference to the mechanical endurance of pinion and gear teeth as is present practice. This naturally includes the limits of wear on axle and armature bearings with reference to the proper meshing of pinions and gear teeth. Such limits can only be properly established after careful investigation, which your committee has been unable to make, and would recommend that it be taken up during the coming year. For the information of the members and with a view to promoting discussion on the subject, your Committee takes the liberty of quoting from letters received from two prominent manufacturers of equipment, on this subject as follows:

LETTER NO. 1. 75 *h.p. and under:* Motors of 75 h.p. and under may use three kinds of gears and two kinds of pinions.

Gears: First—Usual steel casting for both solid and split gears. *Second*—High carbon steel oil quenched rims. *Third*—Case-hardened teeth, case hardening to be at least 1/10 in. deep.

Pinions: First—High carbon steel oil quenched. *Second*—Case hardened.

The gears should be of the same characteristics as the pinions. This, however, is only possible in solid gears; split gears should continue to be made of the usual steel casting.

The characteristics of the high carbon steel should be:

Tensile strength	115,000 to 120,000 lb.
Elastic limit	80,000 to 85,000 lb.
Reduction in area	30 to 35 per cent.
Elongation	13 to 15 per cent.

For the high carbon, the above physical properties can be obtained and the above specifications should be rigidly held to.

Over 75 *h.p.* For motors of over 75 h.p., only the high carbon steel oil quenched should be used for both gears and pinions.

Case Hardening. A case hardening of a thin skin of say, 0.010 in. is of small value. The case hardening should extend to at least 1/10 in. or to a depth to which the teeth are allowed to wear.

Allowable Wear of Pinion and Gear Teeth. This is limited, first by noise, and second by strength of the material of the teeth. High carbon steel maintains elastic limit of 80,000 lb. all the time. In order to get good case hardening it is necessary to start with a lower carbon steel, and when the case hardening is worn off, the elastic limit of the material left is about one-third of the value of a high carbon oil quenched steel. Thus, the limit of wear from the standpoint of strength may be considerably less with the case-hardened pinion than with high carbon oil quenched steel. A high carbon steel tooth apparently may be worn until the thickness at the pitch line is two-thirds of the original thickness. The limit of wear for a case-hardened pinion should be slightly less than the depth of case hardening. As affecting the strength of the pinion and gear teeth, the proper fit of these teeth should be maintained. Excessive wearing of armature and axle bearings not only gets the pinion and gear out of mesh, but causes the teeth not to fit entirely across the face. The gear and pinion are, therefore, at an angle to each other, bringing a greater strain on the end of the teeth nearer the motor. It seems that a good limit for the wear of bearings is that they should not be worn in any place to a greater extent than 3/64 in. measured from the center, or in other words, radially. It would not be safe to measure this as 1/8 in. in diameter for the reason that the bearings might be worn on one side. The rapid development of material and treatment of the materials, together with the relative costs and life of gears and pinions, may radically change these suggestions in a year or so. Some of the points on which there is development are, material, treatment of material, and shape of tooth.

LETTER No. 2. *Material.* From a wearing standpoint, material for gears and pinions should be hard, so as to withstand the severe punishment of the line contact load of the two teeth in contact. This hardness, however, must not be obtained at the sacrifice of ductility, as the shocks on gear and pinion teeth due to reversing, flashing and back-lashing, due to worn teeth and bearings or the jumping of the wheels at high speed on rough track, is very great and extreme hardness of course generally tends toward brittleness. The material which has been found most reliable so far, is a special treated carbon steel. Gears and pinions of this type are showing extremely good life and freedom from breakage under very severe service. Case-hardened gears and pinions are being tried on a fairly large scale and give promise of good results. They are more apt to be noisy at first, owing to distortion in treatment, which appears to be unavoidable. However, their greater freedom from wear will make them less noisy during their life than other types of gears. Where case-hardened gears are used, great care must be taken to retain sufficient ductility in the material under the case hardening to prevent breakage. They have the advantage of retaining nearly the full tooth size and proportions through their life, as the wear is very slow, until the case is worn through, but as soon as it wears through on some teeth, these teeth will wear rapidly, thus making the gear noisy and ending its usefulness.

Limit of Wear. In general it is considered good practice to wear pinion teeth until they measure 1/16 in. flat at the tips. It would probably be better to consider the amount of wear at the pitch line rather than at the extreme tip of the tooth, and it is probable that with the standard pitch of gears now used 3/32 in. on either side of the tooth is about the limit. With material sufficiently hard to prevent grooving in the service in which it is used, the teeth should remain very close to the true involute during their life, so that with the exception of the increased back-lash, they should run and wear well until the above limit is reached. If the axle bearings are allowed to become worn, so as to have more than 1/16 in. play, the pitch line separates so as to wear the tip of the tooth more than the root, with the result of having bad wear on the new pinions assembled with the old gears, especially when, as is usually the case, new bearings are installed at the same time as the new pinion. I think that it is impossible to place too great emphasis on the advisability of keeping down the play in the axle bearings, especially on heavy, high-speed equipment. Careful attention to the lubrication of gears and to keeping up the axle bearings will far more than repay the operators in the increased life and cost of maintenance of gears and pinions and freedom from noise and consequent loosening of the entire truck."

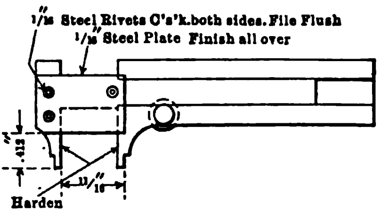

1/16" Steel Rivets C's'k.both sides. File Flush
1/16" Steel Plate Finish all over
.412"
11/16"
Harden

FIG. 81.—Gear tooth caliper.

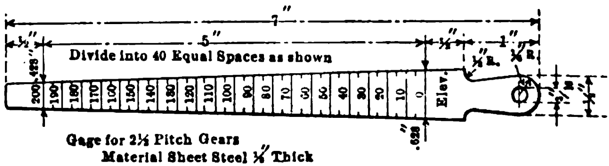


FIG. 82.—Gear tooth wear gage.

Measurement of Gear Tooth Wear. The following method of measuring gear and pinion tooth wear on the Brooklyn Rapid Transit System was devised by Mr. W. E. Johnson: An ordinary sliding caliper (Fig. 81) which is provided with a stop plate to give the required distance from the top of the tooth to the pitch circle, is used to obtain the thickness of the tooth. The wear is then obtained directly by inserting a tapered gage (Fig. 82) between the jaws of the caliper. This gage is based on the same principle as a tapered screw or wire gage. The zero point represents the theoretical thickness of the new tooth, and the gage is tapered 0.04 in. per inch of length. Full ⅛ in. graduations, with intermediate partial graduations, are provided on one face of the gage, and as each full graduation represents a difference in thickness of 0.01 in., readings to 0.001 in. can readily be obtained with this gage. The height of the jaws on the calipers will vary according to the pitch and also according to the number of teeth in gear and pinion of the same pitch. Where a comparison in wear between pinions of the same pitch but with different numbers of teeth is required, it may be desirable to have a set of calipers for each type of pinion. As the difference in reading in such cases would be very slight, however, and as they would at any rate be comparative, one caliper usually is satisfactory for each pitch used. Gear tooth calipers which measure the thickness of tooth directly are manufactured.

Treatment of Gear and Pinion Steel. Oil quenching and case hardening. The data used in the following are from a paper by Mr. T. W. Williams before the Central Electric Railway Association, 1910.

Material	Tensile strength, lb. per sq. in.	Elastic limit, lb. per sq. in.	Reduction in area, per cent.	Elongation, per cent.	Hardness
Steel containing about 0.7 per cent. carbon, before treatment.	85,000	40,000	40	18	120
Same, after oil quenching.	120,000	85,000	30	15	300
After case hardening.	140,000	135,000	2 or 3	2 or 3	625

NOTE: The values given for case-hardened material are but approximate.

From these tests it is seen that the oil treatment practically doubles the strength and more than doubles the degree of hardness. Case hardening brings about a greater increase of strength and hardness.

Material of Meshing Gear and Pinion Should be the Same. In the paper referred to above, Mr. Williams also states that if soft steel gears be run against hard steel pinions, or *vice versa*, the softer surface becomes charged with the gritty material which finds its way into the gear case, and when so charged this surface grinds away the harder surface, but when hardened gears and pinions are run together this trouble does not seem to be so great.

Gears Having Teeth of Special Design ("Stub-tooth" Gears). Where gears are constantly subjected to extraordinarily great strains it may be necessary to use gears having teeth of special design. Such a design is shown in Fig. 83 from the practice of the Aurora, Elgin and Chicago Railroad Co. In the development of these gears the old ratio of 1.6 was not changed. The first gears used were three-pitch, having fifty-eight teeth in the gear, thirty-six teeth in the pinion and a 5-in. face. As traffic developed and the service requirements became more severe, breakage of teeth in these original gears called for a design with a stronger tooth, and

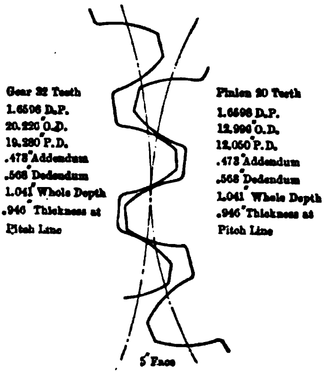


FIG. 83.—Stub-tooth gears.

accordingly the pitch was changed to 2.489. This gave forty-eight teeth on the gear and thirty teeth on the pinion. Although this latter type gave a larger tooth section, trouble from breakage was still experienced. The latest type of tooth has been in service on a number of cars for a period of 9 months (1914), and no breakage has occurred. This gearing has a diametrical pitch of 1.6598 and has an exceptionally big blunt tooth which is very rugged.

Double-pinion Drive for City Cars. In the double-pinion drive a pinion pressed onto each of the extended ends of the armature shaft meshes with a gear mounted on the axle just inside of the car wheel. This arrangement reduces distortion and thus reduces bearing and wheel flange wear. Mr. A. A. Blackburn, Chief Engineer, Belfast (Ireland) City Tramways, Electric Railway Journal, 1914, gives the following points relative to the use of double-pinion drive based on 4 years of experience with it. Cars have been sent in to the shop, on an average, about every 9 months for wheel flange wear, but the cars fitted with the double gears stay in service for an average period of 11 months before being sent into the shop. This is attributed to the fact that the four gears drive the truck parallel on the track. These cars also climb hills better, as the wheels have not the same tendency to slip. The trucks do not have the same corner-thrust action, consequently they keep more square and the wheels wear more evenly. Motormen report that the double-geared cars run much steadier and start easier. In starting the car there is not the same jerk as with single-geared trucks, therefore there is not the same wear on gears and pinions. These cars have run on every service and over every route on the system, and careful meter tests show that the energy consumption per car mile is slightly less. Armatures and motor-suspension bearings wear more evenly and last longer. Commutators do not flash across and they wear better. In fitting the double gear wheels to an axle, a certain amount of care is necessary to see that the gear-wheel teeth are parallel and are perfectly in line one with the other. To obtain these results everything depends upon the accuracy with which the gear-wheel keyseats are cut, as the least alteration in the keyseat or key throws the gears out of mesh. The armature shaft is lengthened out at the commutator end to suit the extra pinion, and the same care must be observed here as with the gears, that is to say, the keyways in the pinions must be cut exactly parallel one with the other. Gears and pinions are supplied with keyseats accurately machined out for this purpose, but slight errors will sometimes arise. Therefore all gear wheels are tested before fitting, by placing two gear wheels together on an axle fitted with a long key. By this means it is possible to see if the gear-wheel teeth and keyseats correspond. Pinions are tested by a similar means. A short piece of axle is turned with a taper at each end, and fitted with two keys. Two pinions are then pushed together until they meet. It is then possible to see at a glance whether the teeth are in line. Occasionally a gear key will have to be side-stepped to permit moving the gear wheel around until the gear teeth are in line, and when this has to be done the procedure is as follows: First of all, one gear is fitted firmly into position, then the second gear is placed over its keyseat, from which the key has been removed, and then the gear is carefully adjusted by means of a steel T-square, into the blades of which are cut slots which fit over one tooth in each of the two gears. The amount of side-step or offset required by the key can be seen at once from the relative position of the keyways in the shaft and in the gear.

Bearings

Liners in Old Motor Armature Bearings. (A.E.R.E.A. Proposed Practice.) Regarding the possible advantage of substituting bronze armature liners for cast iron, babbitt lined, on the oldest types of motor, general opinion indicates that the advantages obtained would not ordinarily warrant the expense of changing. General experience shows that in city service cast or malleable iron armature liners, with a lining of high-class tin base babbitt, give satisfactory results.

Armature Dropping on Pole Pieces. (A.E.R.E.A. Proposed Practice.) Where older types of motor are used in high-speed interurban service, and give trouble from armature dropping on the pole pieces, it is recommended that special attention be given to improving lubrication, and that a trial be given of displacing the iron liner having a thick babbitt lining, with a bronze liner having a lining not over 1/16 in. thick of high-class tin babbitt. It is the general opinion that it is imperative for high-speed interurban service that a hard, high-class tin babbitt be used.

Axle Liner. (A.E.R.E.A. Miscellaneous Methods and Practices.) It is recommended that where total thickness of axle liners is 3/4 in. and over, a malleable iron shell be used, with not less than 3/16 in. babbitt lining securely anchored both on flanges and bearing surface. That where total thickness of axle liner is 1/2 in. or less, a high-class bronze or bell metal be used. That for liner of thickness between 3/4 in. and 1/2 in. a somewhat cheaper bearing metal of hard brass may be used with economy. All brass or bronze axle liners should be lined with a genuine babbitt or tin lining 1/16 in. thick, securely soldered.

Bronze and Brass. (A.E.R.E.A. Miscellaneous Methods and Practices.) The following formulas were submitted by the 1908 committee on Maintenance and Inspection of Electrical Equipment, A.E.R.E.A. as having been "highly spoken of for durability and satisfactory service:"

Bronze: Copper, 80 per cent.; tin, 11 per cent.; lead, 8 per cent.; phosphor-tin, 1 per cent.

Brass: Copper, 77 per cent.; tin, 5 per cent.; lead, 6 per cent.; zinc, 12 per cent.

Maintenance. General sizes of bearings for economical maintenance. The following is from a reply in the Electric Journal, 1910: The practice is sometimes followed of supplying a stock of bearings standardized to, say, three sizes differing slightly in diameter. The larger size of bearing is used for new equipment, the second size for equipments in which the journals have worn sufficiently to require repair, whereupon the latter are turned down to a size corresponding with the second standard size of bearing;

the next smaller size of bearing is used in a similar way for equipments requiring a third renewal, etc. The economy of a given method of maintenance depends upon the number of equipments of a given type that are involved and also upon the total number of equipments in operation.

Babbitting. Method of setting up for babbitting and allowances to be made for oil space and irregularities. (From the same source): A set of bearings should be clamped in a carefully made jig chuck after casting, and bored to the following allowances: Solid bearings, 0.002 in. per inch diameter of bearing; split bearings, 0.003 in. per inch diameter of bearing. It should not be necessary to test for alinement in the motor frame if the proper tools are used.

Babbitt. (A.E.R.E.A. Proposed Practice.) It is desirable that a road avoid if possible using a large variety of babbitts, and that the number of grades used be as few as possible. Where more than one grade of babbitt is used, it is of utmost importance that they be kept separate.

Advantage of Tin Babbitt. (A.E.R.E.A. Proposed Practice.) A pronounced advantage in using genuine tin babbitt is found in that the metal may be remelted repeatedly without deterioration. In remelting genuine tin babbitt, it has been found desirable to introduce a raw potato into the melting pot, to stir up the molten babbitt and assist in oxidizing out lead or other impurities.

Babbitt Used in Practice. (A.E.R.E.A. Proposed Practice.) The following formula (a) is principally used, and formulas approximating (b) are frequently used by operating roads:

	Tin	Antimony	Copper
(a)	83⅓ per cent.	8⅓ per cent.	8⅓ per cent.
(b)	88.9 per cent.	7.4 per cent.	3.7 per cent.

Rules for Rebabbitting Bearings. The following detailed instructions are from the practice of the Cleveland, Painesville & Eastern Railroad Co.:

Prepare the shell by melting out all the old babbitt and chip and file the edges of the lubrication holes and oil groove recesses, leaving them clean and smooth; then heat the shell sufficiently to drive off any moisture. Rub the surface to be tinned with a cloth saturated with a zinc chloride soldering solution. Coat any machine part of the shell not to be tinned with a thin mixture of graphite and water. Dip the shell thus prepared in a pot of half-and-half solder which should be kept at a temperature between 315 and 370 deg C. Leave the shell in the solder until it is just hot enough for the solder to run off, leaving a thin coating. Remove the shell from the pot and thoroughly rub the surface to be coated with a swab saturated with the zinc chloride soldering fluid, making sure that all parts have an even coating. Rub the tinned surface with clean waste to remove any oxide or other foreign matter and brush the graphite from the untinned parts. The mandrel should be large enough to leave after babbitting at least 0.020 in. for finishing. Close the lubrication holes with a cylindrical piece of sheet iron, pouring them solid with the lining, and then clean them out afterward with a hot iron. The temperature of the blocks at the pouring should be the same as that of the shell. The babbitt should be kept at a temperature between 350 and 475 deg. C. Dip the metal from the bottom of the pot to insure thorough stirring. To avoid pocketing air pour in a steady stream, about $\frac{3}{16}$ in. in diameter, directly down around the mandrel. Perform all operations from tinning to pouring, inclusive, as rapidly as possible, not allowing the bearing to cool. Blow holes should be sealed with a hot soldering iron, using the same babbitt. Remove the babbitt from the lubrication holes with the hot iron, file the edges smooth and clean out the oil grooves. Finish bearing in accordance with design.

Oil Lubrication and Life of Armature Bearings. An article in the Electric Railway Journal, 1913, by Mr. N. W. Storer states: "With old grease lubrication it was no uncommon thing for armature bearing shells to be replaced after 3000 miles of service. The life of the bearing on the No. 101-*B*-2 motor may be anything up to 300,000 to 400,000 miles. This extraordinary result is due to the excellent design of the bearing, which has the waste packed against the shaft on the low pressure side, with pressure of a column of waste over it, and the oil fed from below, coming from the well, which may be gaged at any time to see that the oil is kept at the economical level. This type of bearing is now universally adopted. It is scarcely necessary to add oil to the bearings more than once a month, so that not only is the cost of lubrication reduced to a negligible quantity, but the cost of maintaining the bearings and the loss due to the armature getting down on the pole pieces, which was a fruitful source of expense with the old bearings, have been practically eliminated."

Features of Efficient Railway Motor Lubrication. The following three lubrication features are found in modern railway motors: (1) Bearings well lubricated by the use of oil-soaked waste. (2) Separate oil well for gaging depth of oil and for receiving fresh oil. (3) Efficient oil throwers as a protection against the oil reaching the interior of the motor.

Rule for Packing Journal Boxes, Motor Axle and Armature Bearings with Oil and Waste. (A.E.R.E.A. Proposed Practice.) (For preparation of oil and waste see page 323.) Inspect the boxes and bearings and see that dust collar and guard and box cover are in good condition and as nearly dust proof as possible. See that journal bearings are not so badly worn that the two outer edges touch the journal, as a bearing in this condition will act as a scraper and a hot-box will result. Also see that there are no threads or waste between the bearing and journal. Place the packing bucket close to the journal box that is to be packed so that no surplus oil will fall to the ground. The first waste applied should be in the form of a roll and packed tightly in to the rear end of the box for the purpose of retaining the oil and excluding the dust and dirt from the back of the box. The waste should then be placed between the bottom of the journal and the bottom of the box and packed firmly enough to form a good wiping contact with the journal, but not so tight as to roll or wedge. The waste placed at the sides of the journal should never be placed above its center, and should lie rather loose. Wipe all surplus oil and waste threads from the mouth and edges of the box and close the lid tightly. The above rules apply to motor axle and armature bearings, with motors designed for this type of lubrication. Boxes should be packed within about ¼ in. of the top and all springs, bolts and covers should be examined to see that they are closed tightly and that they are as nearly dust proof as possible.

Grease Lubrication of Motor Axle Bearings. (A.E.R.E.A. Proposed Practice.) In city service it is recommended that motor-axle bearings, where grease is used in the older types of motors, shall be lubricated every 2 days, or about every 300 miles. In high-speed service where grease is used to lubricate the motor-axle bearings, they should be lubricated daily. See that grease is pressed down so as to form a firm contact with the axle and take sufficient amount to fill the cup within ¼ in. of the top. See that grease-cup cover is tightly closed. See that hinge bolt and springs are in such condition as to keep cup cover firmly closed.

Oil Lubrication of Motor-axle Bearings. (A.E.R.E.A. Proposed Practice.) Motor-axle bearings in city service where the newer types of motors are used, that are designed for oil and waste lubrication, should be lubricated weekly, or about every 1000 miles. Motor-axle bearings in high-speed service with the later type of motors, designed for oil and waste lubrication, should be lubricated every 3 days, or about every 1000 miles.

Frequency of Lubrication of Armature Bearings. (A.E.R.E.A. Proposed Practice.) The following rule is recommended for the lubrication of armature bearings: Where grease is used in the older type of motor in city service, the armature bearings shall be lubricated every other day, or if on a mileage basis, every 300 miles. Where oil cups are in use on the older types of motors, the committee believes the lubrication should be left to the judgment of the operator. In high-speed service where grease is used as a lubricant in armature bearings on the older types of motors, the armature bearings should be lubricated daily, or if on a mileage basis, every 300 miles. In high-speed service where oil and waste are used as lubricants in the newer types of motors, armature bearings shall be lubricated every 3 days, or about every 1000 miles.

Gaging Amount of Lubricant in Motor Bearings. (A.E.R.E.A. Proposed Practice.) It is recommended that where motor is designed so that height of oil in reservoirs can be gaged, that gaging be invariably done as a part of the oiler's inspection; that oil levels be maintained at a height that experience shows is most economical and that where no provision is made in the design of motor for gaging oil, wherever possible, a home-made tube or other device be installed for such purpose.

Quantity of Car Oil Used in Practice. The following table showing amounts of oil required for the lubrication of armature bearings, axle bearings and journal bearings is from a statement in Aera, 1912, of lubricating material used in surface car shops during October and November, 1911, Brooklyn Rapid Transit Co.:

Shops	Months	Number of cars	Number of motors	Total mileage	Average miles per car per day	Number of armature bearing oilings
Ridgewood	Oct.	346	860	784,149	73.2	11,404
	Nov.	346	860	774,826	72.3	11,440
East N. Y........	Oct.	355	1,016	907,573	82.7	12,988
	Nov.	355	1,016	885,975	80.6	13,002
Maspeth..........	Oct.	240	608	547,415	74.0	7,032
	Nov.	240	608	528,277	71.0	6,982
58th Street	Oct.	216	490	528,380	79.2	8,752
	Nov.	216	490	509,361	76.2	8,748
Ninth Ave.	Oct.	394	982	826,288	67.8	14,802
	Nov.	394	982	797,204	65.3	14,940
Flatbush.........	Oct.	160	420	427,662	86.4	6,288
	Nov.	160	420	421,615	85.1	6,274

Shops	Number of axle bearing oilings	Number of journal oilings	Armature bearings + axle bearings + journal bearings oilings	Total gallons car oil	Car oil-gills per average bearing oiling	Car oil-gills per 1000 motor miles
Ridgewood ...	11,184	666	22,254	475	0.653	7.57
	11,344	748	23,532	635	0.864	9.97
East N. Y....	12,860	958	26,806	601	0.717	7.03
	12,784	828	26,614	546	0.656	6.48
Maspeth	6,972	474	14,478	290	0.641	6.17
	6,936	404	14,322	319	0.712	7.13
58th Street ...	8,696	362	18,010	403	0.717	10.55
	8,616	372	17,936	361	0.665	9.77
Ninth Ave ...	14,754	1,092	30,648	590	0.617	9.44
	14,674	916	30,530	590	0.619	9.63
Flatbush.	6,188	488	12,964	370	0.914	10.03
	6,180	498	12,952	355	0.877	9.82

Adaptation of Oil Lubrication to the Older Types of Railway Motors Originally Designed for the Use of Solid Lubricants. The 1908 Committee on Maintenance and Inspection, Am. El. Ry. Eng. Assn., recommended that oil be used to lubricate armature and motor axle bearings wherever it is possible to do so by the use of oil cups. It also stated that users of oil in the older types of motors are obliged to inspect and lubricate their armature and axle bearings daily. Relative to the mileage between lubrications of the older types of motors adapted to the use of oil, the statement of that committee is: "Where oil cups are used for the lubrication of motor-axle bearings on the older type of motors, your committee has decided that owing to the different and numerous types and conditions under which they are used, the operators would be the better judges in this respect.”

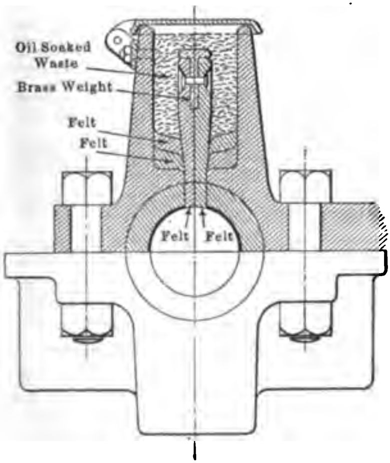


Fig. 84.—Grease cup arranged for oil—Columbus.

A.E.R.E.A. Proposed Practice. The first step in the line of reformed lubrication was to introduce an oil cup that would slip inside the grease cup. The devices for feeding the oil have been many and various; some with constant feed depending upon the capillary attraction of wicks or yarn strands; others with more or less automatic features. Doubtless some of these types of oil feed are satisfactory, but judging from the growing tendency to adopt a more positive form of lubrication for motors, it would seem that the early forms of oil cup are not ideal for reliability and good results. The tendency is not to depend upon the capillarity of a single thread or a small wick to oil a motor bearing, but to have some medium, such as oil-soaked felt or waste put into actual physical contact with the journal. In Aera, 1912, Mr. I. F. Uffert, Master Mechanic, United Traction Co., Albany, N. Y., states: “From my experience with the older types of motors such as GE-57, 1000, 800, 67, 52 and 54, also West. 3, 12-A, 38-B, 49, 56, which were designed for grease, I find the best way of lubricating these motors with oil is to put a piece of felt into the slot of the bearing, then lay another piece of felt over same, but covering entire bottom of grease cup, then fill remainder of cup with wool waste packed in quite tight on top of felt. Felt next to shafts should be removed at least once a month, as it becomes gummed up and oil will not feed through. I have found

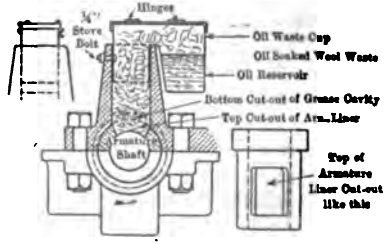

Hinges
¼" Stove Bolt
Oil Waste Cup
Oil Soaked Wool Waste
Oil Reservoir
Bottom Cut-out of Grease Cavity
Top Cut-out of Arm. Liner
Armature Shaft
Top of Armature Liner Cut-out like this

Fig. 85.—Grease cup arranged for oil—Chicago & Milwaukee.

this far superior to oil cups and the use of all wool waste as the felt will not allow the oil to feed through too fast." For details of oil cups, felt and waste fillers for the adaptation of oil lubrication to motors originally designed for grease, see Figs. 84, 85 and 86.

Preparing Oil and Waste for Lubrication. (A.E.R.E.A. Proposed Practice.) A good grade of wool waste should be used, that has a sufficient elasticity to act in a spongy condition after it has been saturated and drained, and also of a sufficient carrying capacity to act as a wick or feeder from the bottom of the box to the journal which is to be lubricated. The oil should also be of a good grade and suitable for the purpose. The waste should be picked apart and saturated in oil, not less than 48 hours before using, allowing 5 pt. of oil to 1 lb. of waste, and the oil should be of such a temperature as to flow freely. Waste should then be drained or wrung out, remembering that it is to be used to act as a sponge or wick rather than a hard solid mass with oil covering it. The waste should be in such condition that when pressed in the boxes the oil will not overflow and run out over the dust guards or opening in the front of the box.

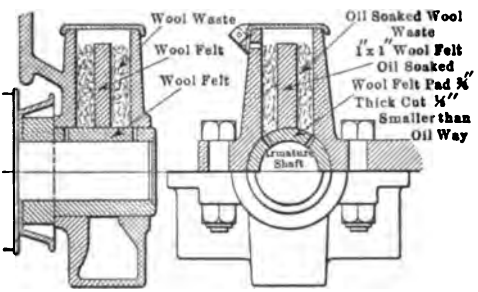


Fig. 86.—Grease cup arranged for oil—South Bend.

Inspection and Lubrication of Gears and Pinions. (A.E.R.E.A., Miscellaneous Methods and Practice.) It is recommended that there be an inspection of gears and pinions each 1000 miles, supplying lubricant if needed, believing that a small quantity of gear grease applied frequently will insure a better economy of lubricant than heavy doses administered at long intervals. Attention is also called to the higher duty required of pinion material on the larger sizes of motors, as, for instance, a 40-h.p. motor pinion has a 5-in. face while a 200-h.p. motor has but 5.25-in. face. It is therefore of vital importance that consideration be given to pinion material being of quality suitable for the higher duty.

Gear lubricant comes under the following heads: A—Heavy Oil or Fatty Grease, containing no graphite; B—Adhesive Gear Compound (non-fatty); C—Graphite Grease. Practice would indicate that an adhesive gear compound (non-fatty) is in favor with nearly all the larger city lines and nearly all the interurban lines, while the smaller city lines using small motors are in favor of a heavy or fatty grease or a graphite grease. This is undoubtedly due to conditions. The congealing of an adhesive gear compound during low temperature would, no doubt, be very noticeable, especially with small equipments, where car houses are not heated. This would also have a tendency to show up in power consumption under the conditions above mentioned. Under the above conditions, both "A" and "C" have the advantage in low temperature, but during the warmer months there is little or no difference. The use of adhesive gear compound containing wood pulp, cork chips or similar substances, tends to overcome noise to a great extent, and it is therefore recommended where conditions are favorable.

In city service, with motors of 50 h.p. or under, where the "A" or "C" lubricant is used, 2 lb. should be applied to each gear case every 30 days. Under similar conditions where "B" is used, 1 pt. should be added to each gear case every 15 days. In high-speed service, with motors of 50 h.p. or more, using "A" or "C" compound, 3 lb. should be applied to each gear case every 30 days. Under similar conditions where the "B" compound is used, 1½ pt. is specified to each gear case every 30 days, but if, on inspection, gear and pinion have sufficient lubrication, none need be applied. The function of a gear lubricant is to provide a thin film of lubricant on the pitch line of the teeth, so that the metals do not at any time come in direct contact. Since a satisfactory gear lubricant reduces friction, its use results in a reduced energy consumption and a reduced maintenance cost. It is also conducive to the quiet operation desirable for satisfactory city service. The proper lubricant should be an intermediate between what is commonly termed a "short-gear grease" and which is nothing more or less than a hard oil, and a sticky, gummy substance which calls for increased power.

Attention is called to the fact that a good many of the troubles for which gear grease is blamed are due to loose axle bearings and axle-bearing collars. Loose axle bearings permit the gear to fall away from the pinion, producing poor meshing of the teeth and climbing of the pinion on the gear, and the consequent establishing of a new pitch line at a point not arranged for it in the design of the pinion. Badly adjusted and neglected collars cause the pinion and gear to work out of line. This causes them to wear unevenly, strike gear pans on straight track, and on curves to run on the points not in regular contact, thereby making an objectionable grinding noise. These are points which no gear grease can be expected to take care of. Where adhesive gear compound is used it is recommended that it be applied more often and in smaller amounts during the winter months, the idea being to let the gear just come in contact with the grease in the bottom of the case. Where the adhesive gear compound is used it should be specified that the material remain reasonably flexible at all temperatures, that the compound shall not dry out, become lumpy or deposit on the gear case in the shape of a hard crust.

Period between Times of Gear Lubrication in Practice. The following table is from data given in the report of the Committee on Electrical Equipment, A.E.R.E.A., 1907:

	Period between lubrication							
	Inspect weekly, lubrication when necessary	1 wk.	10 dy.	2 wk.	1 mo.	6 wk.	2 mo.	3 mo.
Number of roads.	1	6	1	4	6	2	1	2

Amount of Gear Lubricant Consumed in Practice. The following table is made up of data from the statement of lubricating material used on surface cars of the Brooklyn Rapid Transit Company during October and November, 1911, Aera, 1912.

Shops*	Month	No. cars	Total gear or motor mileage	No. of gears (total)	Total pounds gear grease	Gear grease, pounds per case	Gear grease, pounds per 1000 gear miles
Ridgewood....	Oct...	346	2,013,956	860	280	0.326	0.1395
	Nov...	346	2,039,132	860	350	0.407	0.1715
East N. Y.....	Oct...	355	2,732,248	1,016	1,030	1.013	0.3780
	Nov...	355	2,688,530	1,016	735	0.723	0.2735
Maspeth......	Oct...	240	1,504,998	608	510	0.838	0.340
	Nov...	240	1,432,686	608	195	0.321	0.1365
58th Street....	Oct...	216	1,220,714	490	833	1.703	0.683
	Nov...	216	1,183,988	490	814	1.660	0.690
Ninth Ave.....	Oct...	394	2,001,918	982	750	0.764	0.375
	Nov...	394	1,962,606	982	814	0.830	0.416
Flatbush......	Oct...	160	1,179,278	420	1,190	2.835	1.018
	Nov...	160	1,155,474	420	800	1.905	0.696

Suspension of Motor and Transmission. (See also pp. 579 and 580.) The following classification and illustrations of some of the methods of suspending motors and transmitting the tractive effort from motor to driving wheel are from a paper "The Design of the Electric Locomotive" by Messrs. N. W. Storer and G. M. Eaton, A.I.E.E., 1910:

a. Gearless motor with armature pressed onto driving axle. "New York Central." Fig. 87.

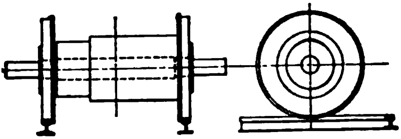


Fig. 87.—New York Central gearless motor.

b. Gearless motor with armature carried on a quill surrounding axle, and driving the wheels through flexible connections. "New Haven Passenger." Fig. 88.

c. Geared motor with bearings directly on axle and with nose

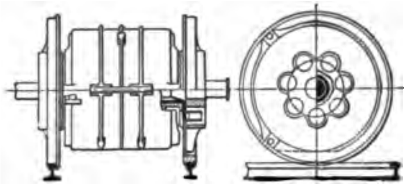


FIG. 88.—New Haven gearless motor.

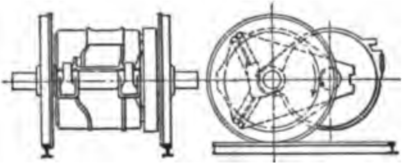


FIG. 89.—St. Clair tunnel geared motor, nose suspension.

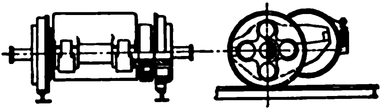


FIG. 90.—New Haven geared motor.

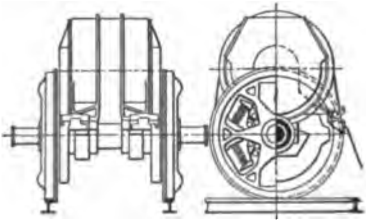


FIG. 91.—New Haven top geared motor.

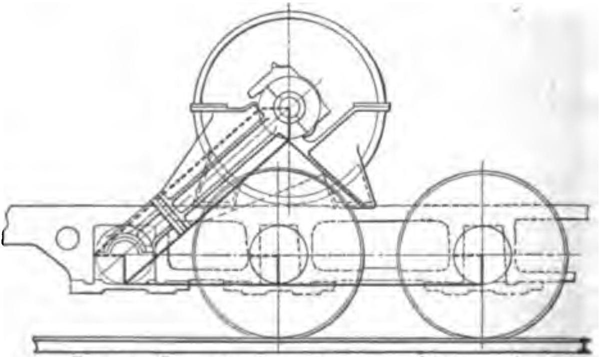


FIG. 92.—Pennsylvania gearless motor with connecting rods.

supported on spring-borne parts of locomotive. "St. Clair Tunnel." Fig. 89.

d. Geared motor with bearings on a quill surrounding axle, and (1) nose supported on spring-borne parts of machine (New Haven Car, Fig. 90) and (2) motor, rigidly bolted to spring-borne parts of

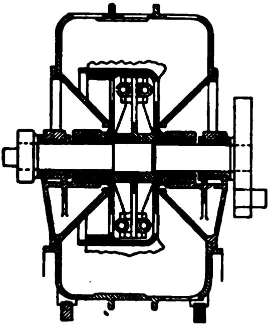


Fig. 93.—New Haven gearless motor.

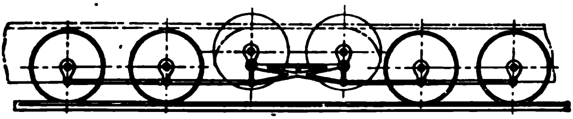


Fig. 94.—Simplon gearless motors with offset connecting rods.

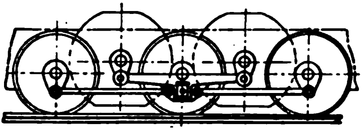


Fig. 95.—Valtellina gearless motors with Scotch yoke.

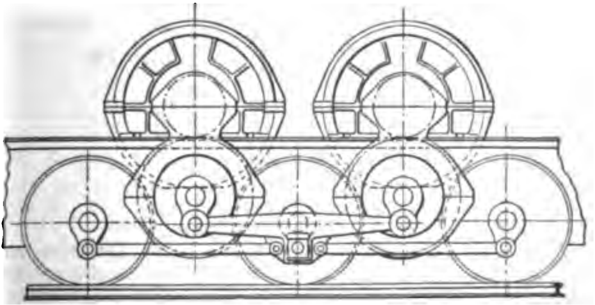


Fig. 96.—Geared motors with Scotch yoke.

machine, the quill having sufficient clearance for axle movements. "Four-motor New Haven Freight." Fig. 91.

e. Motor mounted rigidly on spring-borne parts, armature rotating at same rate as drivers, power transmitted to drivers through cranks, connecting rods and countershaft on level with driver axles. "Pennsylvania." Fig. 92.

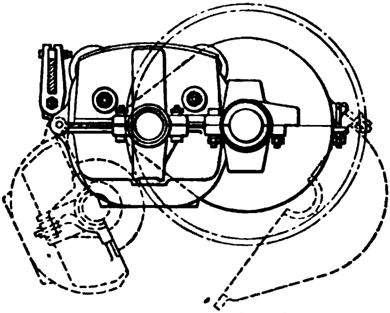
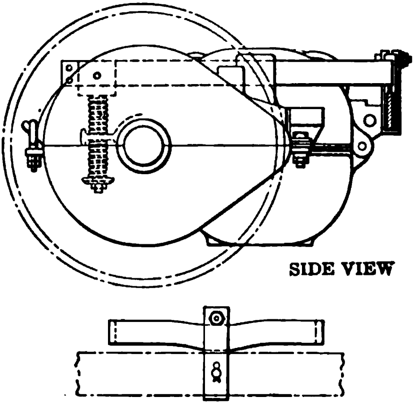


Fig. 97.—Nose suspension of motor.

f. Motor mounting and transmission as in (*e*) but motor fitted with double bearings one part for centering motor crank axle and the other for centering the armature quill which surrounds and is flexibly connected to the motor crank axle. "Two-motor New Haven Freight." Fig. 93.



FRONT VIEW OF CRADLE

Fig. 98.—Cradle suspension of motor.

g. Motors mounted on spring-borne parts, armature rotating at same rate as drivers, power transmitted to drivers through offset connecting rods and side rods. ·Simplon locomotives." Fig. 94.

h. Motors mounted on spring-borne parts, armature rotating at same rate as drivers, power transmitted to drivers through Scotch yokes and side rods. "Valtellina Locomotives." Fig. 95.

j. Motors mounted rigidly on spring-borne parts, power transmitted through gears to counter shafts, thence to drivers through Scotch yokes and side rods. Fig. 96.

Motor Suspension on Cars. *Nose suspension* (*c.* above, and Figs. 89 and 97) is the most common method of motor suspension on motor cars. Springs in the motor nose suspension lessen shocks during starting or sudden changes of torque. Approximately 60 per cent. of the weight of the motor is carried directly on the axles without spring support.

Cradle Suspension (Fig. 98). The total weight of the motor is hung by lugs on either side from a longitudinal horizontal bar which at the back end is spring supported from lugs on the arm which carries the axle bearing and at the front end by a cross beam and the truck frame. This type of suspension is seldom used at present.

Twin Motors (Fig. 99). Two motors of equal capacity are mounted above each axle. Each motor is provided with a pinion and the two pinions of the pair of motors mesh with a single gear which is mounted on a quill surrounding the driving axle. By this arrangement, two small motors, each having twice the rotative speed of one large motor, may be used; therefore, the pair of small motors has practically the same number of electrical parts as one large motor of equivalent capacity. Since each motor of the pair is about half the diameter of one motor of capacity equivalent to that of the pair, the pair may be mounted on a lighter frame and the weight of the end housings may be reduced. The width of the gear required on each axle is but half that required with one large motor of equivalent capacity. Thus the weight of the gear is reduced and a longer, more economical design of motor is made possible.

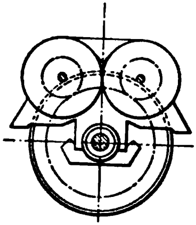


FIG. 99.—Twin-motor suspension.

SECTION V

CONTROLLING APPARATUS

Controllers for Series Motors

Rheostatic Control. Rheostatic control is carried out entirely by making changes in the resistance of the motor circuit to maintain the desired current through the motor during acceleration. In this method there is no arrangement for series-paralleling. Rheostatic control may be used with equipments of one or more motors, but because of the greater energy economy secured by series-paralleling in two or four motor equipments, the use of rheostatic control is practically limited to single-motor equipments. The hand controller commonly used to make the necessary connections for rheostatic control is generally known by its trade name, the type "*R*" controller.

Series-parallel Control. The series-parallel method of control is the method most commonly used with two- and four-motor equipments. In starting a two-motor equipment by this method the two motors are first connected in series and in series with the control resistance, then the control resistance is reduced by steps until the motors are running in series on the working conductor potential. Control resistance is then added as the motors are connected in parallel after which the control resistance is reduced by steps until the motors are running in parallel on the working conductor potential. Four-motor equipments are usually arranged in two groups of two motors permanently connected in parallel with each other and these two groups are controlled as the two motors of a two-motor equipment. There are two general methods of making the transition from series to parallel connections in series-parallel control, one opening the power circuit, while the other leaves it closed.

Type "K" Controller. (Figs. 1 and 2, also Figs. 3 to 10, inclusive, which are from "Electric Car Maintenance," by Mr. Walter Jackson.) The type "*K*" controller does not open the power circuit during transition from series to parallel. This type of controller is in most common use. For the control of the smaller motors the type "*K*" controller is arranged to cut the current off half the motors during transition. This is done by first shunting this half, then disconnecting it before placing the halves in parallel. For the control of the larger motors the type "*K*" controller is arranged to maintain the current in all the motors during transition (see "Bridging Connections," p. 333).

Type "L" Controller. The type "*L*" controller opens the power circuit during transition from series to parallel connections of the motors (Fig. 11). This type of controller is little used.

Type "B" Controller. The type "*B*" controller has the usual power connections and in addition it is arranged to make connections for electrical braking by operating the motors as series generators to excite the electrically operated brakes. This method of

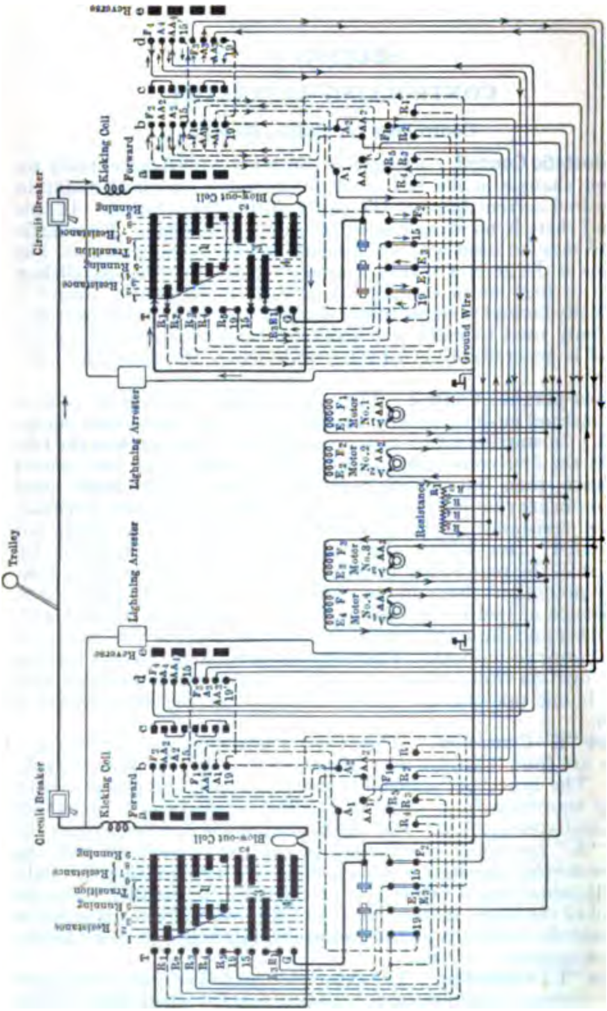


FIG. 1.—Circuits of two K-12 controllers with four motors.

electric braking imposes an additional load upon the motors, thus necessitating larger motors.

Bridging Connections. (Type "K" Controller.) As noted above, the smaller sizes of type "*K*" controller are arranged to cut the current off half the motors during transition from series to parallel connections. This causes a reduction in the tractive effort of the motor equipment during transition. In order to maintain approximately the same current through all the motors, thereby holding the tractive effort approximately constant during transition, a bridging system of connections is used in some of the larger controllers. Fig. 12 shows a typical arrangement for the "bridging" method of series-parallel control; it also gives the

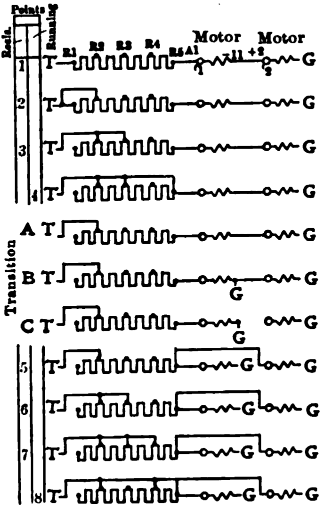


FIG. 2.—Sequence of connections type *K* controller, shunted motor transition.

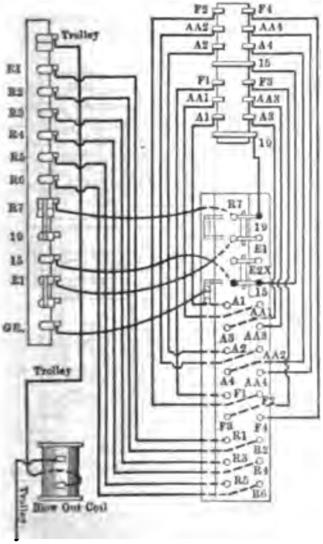


FIG. 3.—Wiring diagram, K-6 controller.

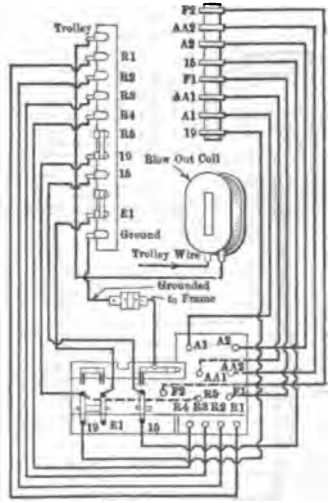


FIG. 4.—Wiring diagram, K-11 controller.

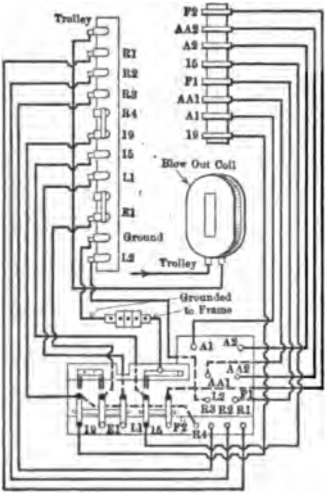


FIG. 5.—Wiring diagram, K-12 controller.

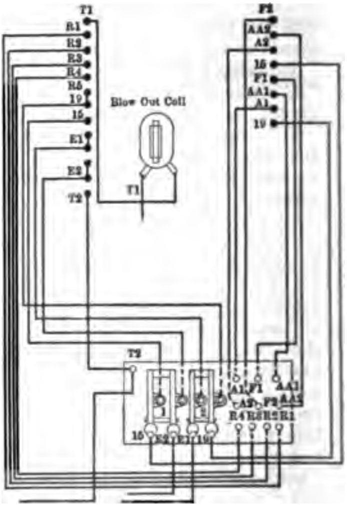


FIG. 6.—Wiring diagram, K-27 controller.

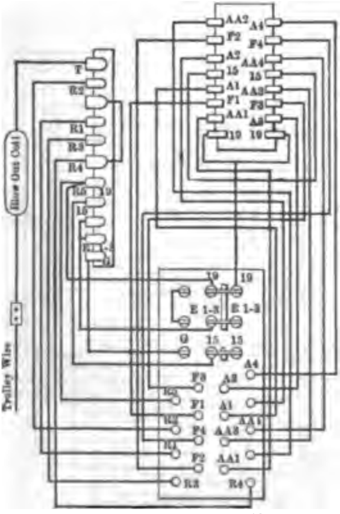


FIG. 7.—Wiring diagram, K-28-B controller.

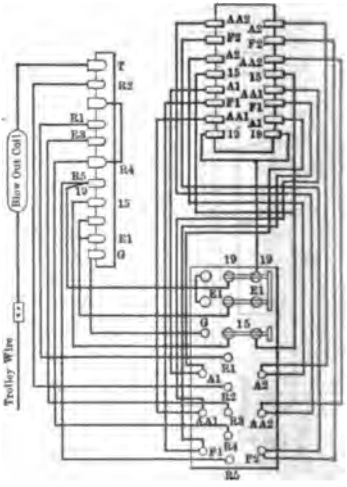


FIG. 8.—Wiring diagram, K-28-L controller.

sequence of switch operation from the starting of the motors in series and in series with the full starting resistance to the point at which the motors are running in parallel on working conductor potential. The circuits during this process are diagrammatically explained by Fig. 13. The sequence of connections for the "bridging" control of a four-motor equipment is shown by Fig. 14.

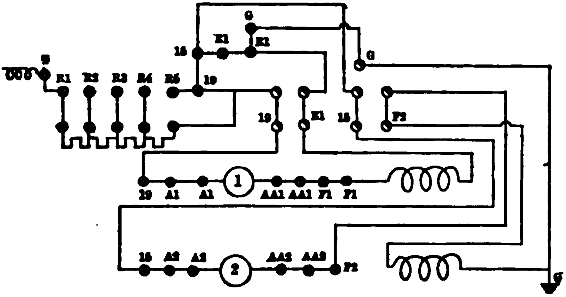


FIG. 9.—Circuit diagram, K-11 controller.

Three-speed Control System. Fig. 15 shows the connections of the Jones patent control system used on the Pittsburgh low floor cars. This control provides three running points, one full series, one series-parallel and one parallel, the points between, where there are one or more idle motors, being simply transition points. This arrangement makes possible the changing of the motors from the full series to full parallel relation without breaking the initial series connections between the motors. These original connections are maintained and the various changes effected by short-circuiting one

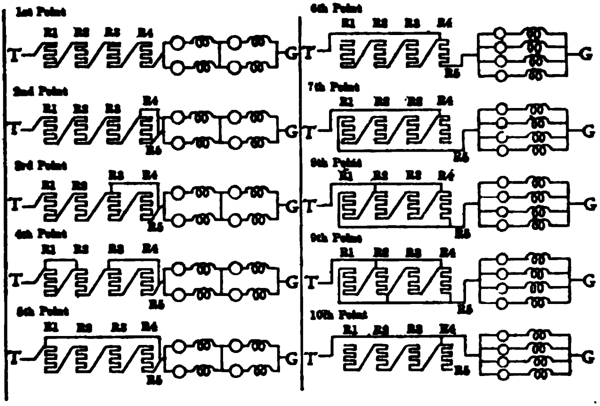


FIG. 10.—Sequence of connections, K-28-B controller.

or more motors and establishing circuit connections of a character to cause the current to flow through both the fields and armatures of some of the motors in a direction reversed to that in which it flowed in the series position. On the first point all four motors are connected in series through a resistance. On the second point this resistance is cut out, which, on a 600-volt circuit, makes 150 volts drop across each motor and makes the second point on the control a running point. The third point is made by closing the switch *C* and opening the switch *A*, *C* closing slightly before *A* opens, which connections short-circuit two motors and place 300 volts across each of the other two. The fourth point simply closes the ground connection to the two idle motors which makes 300 volts across all four motors and parallels the two pairs. Transition is made from this fourth point, which is a running point, to the next running point, which is the seventh, by first providing connections which short-circuit one motor and place one across 600 volts in parallel with the other two in series with 300 volts across each; then short-circuiting another motor with the other two operating in parallel across 600 volts; and then providing the ground connection for the two short-circuited motors, placing all four in parallel across 600 volts. This system is very efficient because there is no external resistance in the motor

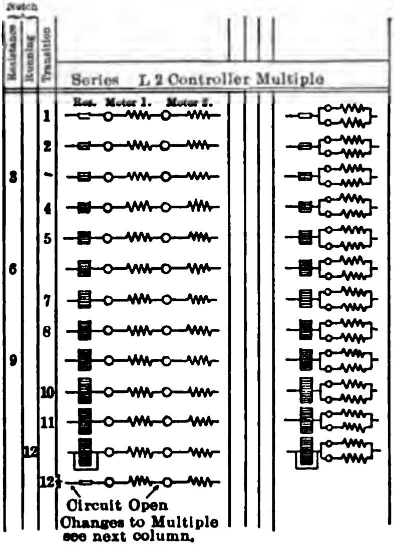
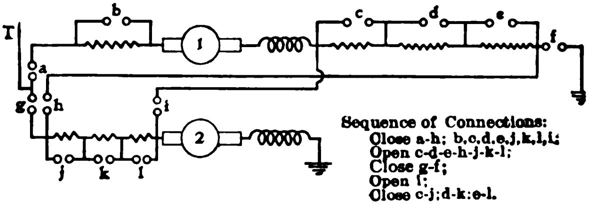


FIG. 11.—Sequence of connections, type *L* controller.



Sequence of Connections:
Close a-h; b,c,d,e,j,k,l,f;
Open c-d-e-h-j-k-l;
Close g-f;
Open f;
Close c-j;d-k:e-l.

FIG. 12.—Circuits of bridging type of control.

circuit beyond the first controller position. It thus also reduces the weight of resistance which must be carried on the car.

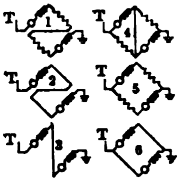


FIG. 13.—Diagram of bridging method of control.

Booster Control (Fig. 16). From description by Mr. Charles Jacquin, Paris, France, of system developed chiefly by M. Legouez and used by the Jeumont Company. M_1M_2 and m_1m_2 represent the armatures and fields of the ordinary direct-current traction motor, the two armatures being permanently operated in series and the two fields being permanently connected in series. The machines F_1, F_2 and F_3 represent the motor-generator set, the functions of which will now be explained. F_1 and F_2 represent a booster group and F_3 a small regeneration dynamo. The booster group itself comprises two commutating machines, F_1 and F_2, the armatures of which are mounted mechanically on the same shaft, one working as a motor and the other as a generator. The functions of these machines are reversible, depending upon operating conditions, but F_1 is always connected in series with the traction motors by a two-way switch 3. By means of switch 4 the armature of F_3, the regeneration dynamo, is joined in parallel with the field coils of the traction motors. This machine serves for varying the excitation of the traction motors. The machine F_2, which operates at a constant speed, is simply a compound dynamo connected across the line, its shunt-exciting circuit being shown as D_1, and its series circuit as D_2. The regulating generator F_1 has two exciting circuits, one being the circuit H which receives a constant current from the line X and the other the circuit E connected

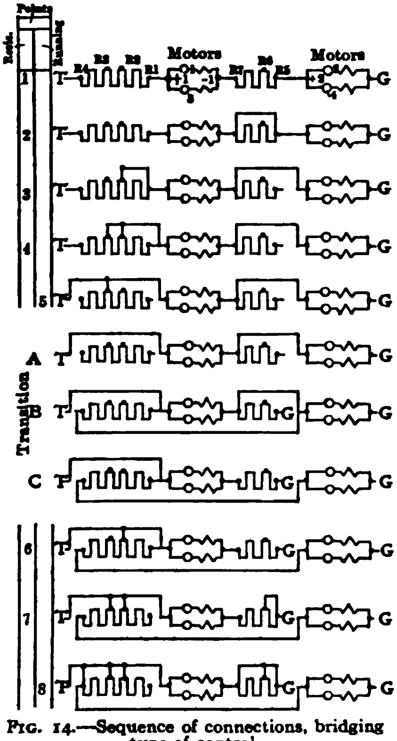
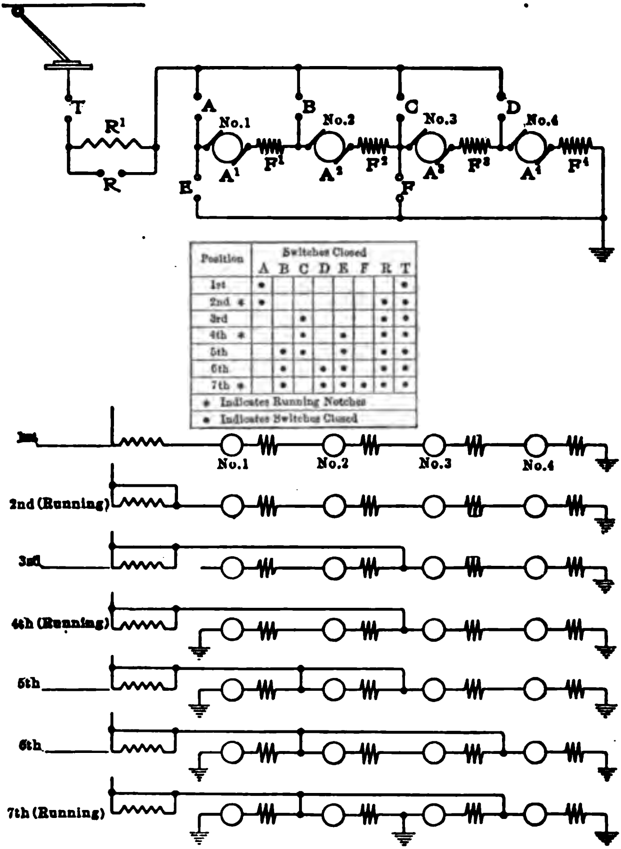


FIG. 14.—Sequence of connections, bridging type of control.

in shunt with its own armature and that of machine F_3. The regeneration dynamo F_3 also has two exciting circuits, one, A, connected directly across the line X to produce a constant excitation, the other, B, connected in parallel with the armature circuit of the regulating dynamo F_1 to give an excitation varying in direction and intensity with the electromotive force of this machine; that is to say, the excitation of F_3 depends upon the speed of the traction motors.



Position	Switches Closed							
	A	B	C	D	E	F	R	T
1st	●							●
2nd ◆	●						●	●
3rd			●				●	●
4th ◆			●		●		●	●
5th		●	●		●		●	●
6th		●		●	●		●	●
7th ◆		●		●	●	●	●	●

◆ Indicates Running Notches

● Indicates Switches Closed

FIG. 15.—Three-speed control, Jones system.

In starting from rest, switch 1 is closed first, the reversing switch of the regulating dynamo being in the proper position. Then the booster group is brought to normal speed with the small rheostat, *rh*, machine F_2 now acting as a motor. Until this moment, switch 3 has been kept open to avoid excessive current in the main motor circuit. As soon as the booster group has attained its normal speed, switch 3 is closed according to the direction of propulsion. The real starting operations follow next. At first the electromotive force of machine F_1 is in a direction to subtract from the main line voltage and thereby to decrease the voltage impressed on the traction motors Under these conditions, F_1 operates as a motor and drives F_2 as generator, which therefore returns energy to the line *X*. Subsequently, as the main traction motors accelerate, the voltage across F_1 is reduced and finally reaches zero, under which condition the two traction motors operate as if in ordinary series connection, receiving the full line voltage. When the higher speed of travel is reached, the dynamo F_2 runs as a motor and drives F_1 as a generator to produce an electromotive force which adds to that of the line until the voltage impressed upon each traction motor is equivalent to tha

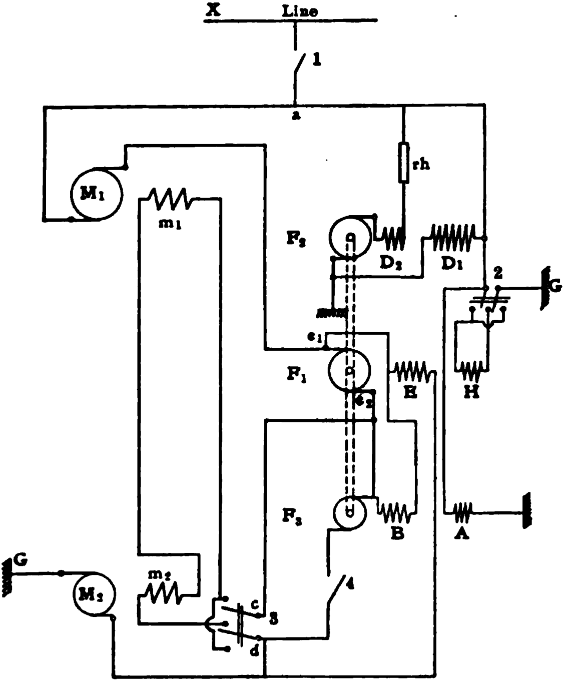
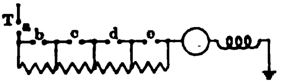


FIG. 16.—Booster control system, Paris.

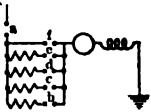
obtained during ordinary parallel connection. By this method, acceleration is obtained without waste of energy or discomfort to passengers. The reverse of the foregoing movements occurs during retardation, the switch 2 being reversed, thereby altering the excitation of machine F_1, varying the electromotive force impressed upon the traction motors and causing energy to be returned to the line.

Resistance Connections. There are two general methods of connecting control resistance in the motor circuit, the series method and the parallel method. In the series method (Fig. 17) all the resistance is connected in series at the beginning and it is cut out of the circuit by short-circuiting sections of it, progressively. By this method much radiating surface is made available during starting. In the parallel method (Fig. 18) the resistance in circuit is reduced by adding resistor sections in parallel, progressively, to the sections already in circuit, thus reducing the total resistance of the circuit and finally short-circuiting all the resistance. This requires smaller switches than the series method. (See Figs. 27–29 inc., for instances of the combination of these two methods.)



Sequence of connections:
Close a,b,c,d,e,f consecutively

FIG. 17.—Series method of connecting control resistance.



Sequence of connections:
Close a;
Close b,c,d,e,f, consecutively

FIG. 18.—Parallel method of connecting control resistance.

Controller Rating. The rating of a controller is based upon the combined nominal 1-hour power rating (see page 221) of the motors it is to control. This rating is generally given for a certain voltage and for a voltage variation from this value, but within the insulation and arc-breaking capacity of the controller, the horse-power capacity of the controller will vary approximately as the voltage.

Reversing Series Motors. The direction of rotation of a series motor may be reversed by inverting the relation of the direction of the current in the armature to the direction of the current in the field. This may be done by reversing the connections to the armature or by reversing the connections to the field. Older types of controllers were arranged to reverse the connections to the brushes, but controllers for use with commutating pole (interpole) motors are arranged to reverse the connections to the field and leave the interpole winding permanently connected between armature and ground, thus securing minimum insulation strains on the interpole winding. Controllers built to reverse the connections to the brushes can be arranged to reverse the connections to the field.

Commercial Drum Type Controllers. Except where noted, the following controller data are for both General Electric and Westinghouse controllers.

Type	No. of motors	Total h.p. 500 volts	Number of points	Approx. net wt. in lb.	Remarks
K-6-A	2 or 4	160	6 series 5 parallel	270	Superseded by K-28-B.
K-6-H	2 or 4	160	6 series 5 parallel	270	Has auxiliary contacts for operating contactors, otherwise as K-6-A, superseded by K-28-J.
K-10-A	2	80	5 series 4 parallel	210	Standard.
K-10-H	2	80	5 series 4 parallel	210	Has auxiliary contacts for operating contactors. Otherwise as K-10-A.
S-3	2	80 to 100	6 series 4 parallel	....	Allis Chalmers.
K-11-A	2	120	5 series 4 parallel	225	Standard. Similar to K-10-A, but with fingers, wiring and blowout of greater capacity.
K-11-H	2	120	5 series 4 parallel	225	Has auxiliary contacts for operating contactors. Otherwise as K-11-A.
K-12-A	4	120	5 series 4 parallel	220	Standard. Similar to K-11-A but with a reverse switch for four motors.
K-12-D	4	120	5 series 4 parallel	220	Has auxiliary contacts for operating contactors. Otherwise as K-12-A.
K-13-A	2	250	7 series 6 parallel	516	Superseded by K-34-D or K-35-G, according to capacity required.
K-14-A	4	240	7 series 6 parallel	550	Superseded by K-34-D or K-35-G, according to capacity required.
K-14-E	4	240	7 series 6 parallel	550	Has auxiliary contacts for operating contactors. Otherwise as K-14-A.
K-27-A	2	120	4 series 4 parallel	225	Standard for metallic return. Supersedes the K-8.
S-4	4	160	6 series 4 parallel	....	Allis Chalmers
K-28-B	4	160	5 series 5 parallel	239	Standard.
K-28-F	4	160	5 series 5 parallel	239	Has auxiliary contacts for operating contactors. Otherwise as K-28-B.
K-29-A	4	160	6 series 5 parallel	265	Standard for metallic return.
K-29-B	4	160	6 series 5 parallel	265	Has auxiliary contacts for operating contactors. Otherwise as K-29-A.

Type	No. of motors	Total h.p. 500 volts	Number of points	Approx. net wt. in lb.	Remarks
K-31-A	4	120	4 series 4 parallel	230	Standard for metallic circuit. Similar to K-27 but with a reverse switch for four motors.
K-32-A	2	80	4 series 4 parallel	220	Standard for metallic circuit. Similar to K-27 but with fingers, blowout and wiring of less capacity.
K-34-D	2 or 4	300	6 series 4 parallel	440	Standard for railway equipments of this capacity. Supersedes K-34-A, K-34-B and K-34-C.
K-34-F	2 or 4	300	6 series 4 parallel	440	Similar to K-34-D, with addition of auxiliary contacts for operating contactors.
S-2	4	300	7 series 5 parallel	....	Allis Chalmers.
K-35-G	2 or 4	200	5 series 3 parallel	267	Standard for railway equipments of this capacity. Supersedes K-35-A, K-35-C and K-35-D.
K-35-H	2 or 4	200	5 series 4 parallel	267	Similar to K-35-G with addition of auxiliary contacts for operating contactor. Supersedes K-35-B.
K-35-M	2 or 4	200	5 series 4 parallel	267	Similar to K-35-G with addition of auxiliary contacts for contactor.
K-36-B	2	120	4 series 4 parallel	220	Standard for railway equipments of this capacity. Supersedes K-36-A.
K-36-C	2	120	4 series 4 parallel	220	Similar to K-36-B with addition of auxiliary contacts for contactor.
K-36-G	2	120	4 series 4 parallel	225	Standard. One motor open circuited in transition.
K-36-H	2	120	4 series 4 parallel	225	Similar to K-36-G with addition of auxiliary contacts for contactor.
K-38-B	2 or 4	300	6 series 5 parallel	455	Standard for railway equipments of this capacity with metallic return. Similar to K-34-D, but arranged for metallic return. Supersedes K-38-A.
K-38-D	2 or 4	300	6 series 4 parallel	440	Standard for metallic return. One-half motors open circuited in transition.
K-39-A	2	120	4 series 4 parallel	225	Standard for railway equipments of this capacity with metallic return. Similar to K-36-B, but arranged for metallic return.

Type	Number of motors	Total h.p. 500 volts	Number of points	Approx. net. wt. in lb.	Remarks
K-39-B	2	120	4 series 4 parallel	229	Standard for metallic return. One motor open circuited in transition.
K-40-A	2 or 4	200	5 series 3 parallel	280	Standard for railway equipments of this capacity with metallic return. Similar to K-35-D, but arranged for metallic return.
S-1	4	200 to 240	7 series 5 parallel	....	Allis Chalmers.
K-44-A	2 or 4	400	7 series 5 parallel	622	Standard. Bridge transition.
L-2-A	2	350	4 series 4 parallel	640	Standard for railway equipments of this capacity. Reverses motor armatures. Must be rewired for interpole motors.
L-3-A	4	600	8 series 8 parallel	982	
L-4-A	4	400	4 series 4 parallel	787	Superseded by K-34 or K-44 according to capacity required.
L-4-E	4	400	4 series 4 parallel	770	Standard for railway equipments of this capacity.
L-4-C	4	400	4 series 4 parallel	770	Similar to L-4-E but has auxiliary contacts for contactor device. Reverses motor armatures. Must be rewired for use with interpole motors.
L-14-A	4	500	7 series 6 parallel	850	Standard for railway equipments of this capacity. Reverses motor armatures. Must be rewired for use with interpole motors.
		Total h.p. 1200 volts			
K-42-A	2	200	6 series 5 parallel	400	Standard. One motor open circuited in transition. Maximum line voltage 1300.
K-42-B	2	200	6 series 5 parallel	400	Has auxiliary contacts for operating contactors. Otherwise as K-42-A. Maximum line voltage 1300.
R-200	2	100	6 series	350	For two 50-h.p., 600-volt motors in series. Maximum line voltage 1300.

ELECTRIC BRAKING CONTROLLERS

Type	Number of motors	Total h.p. 500 volts	Number of points	Approx. net wt. in lb.	Remarks
B–6–A	4	120	4 series 4 parallel 4 braking	335	
B–8–B	4	240	6 series 5 parallel 7 braking	670	Has separate brake handle.
B–18–A	2	80	4 series 4 parallel 6 braking	275	
B–19–A	4	160	5 series 4 parallel 6 braking	430	Has separate brake handle.
B–23–A	2	120	5 series 4 parallel 7 braking	350	Standard for two 60-h.p. motors or less.
B–23–D	2	120	5 series 4 parallel 7 braking	350	Standard.
B–35–A	2	100	4 series 4 parallel 6 braking	280	
B–50–A	4	200	5 series 4 parallel 9 braking	550	Standard for four 50-h.p. motors or less. Has modern construction similar to K–35–D. For 750 volts maximum.
B–51–A	2	200	5 series 4 parallel 9 braking	550	Standard for two 100-h.p. motors. Similar to B–50, but arranged for two motors. For 750 volts maximum.

RHEOSTATIC CONTROLLERS

Type	Number handles	Number points	Number motors	H.p. each motor 500 volts	Remarks
R–9–A	1	8	1	200	Westinghouse.
R–17–A	2	6	1	50	Westinghouse.
R–19–A	....	6	2	50	General Electric.
R–22–A	2	5	2	50	Westinghouse.
R–27–A	1	9	1	75	Westinghouse.
R–28–A	1	5	1	50	Westinghouse.
R–32–A	1	9	1	100	Westinghouse.
R–84–A	1	13	1	200	Westinghouse.
R–86–A	2	5	2	50	Westinghouse.
R–109–A	2	6	2	100	Westinghouse.
R–112–A	2	6	2	160	Westinghouse.
R–113–A	2	6	3	80	Westinghouse.
R–114–A	2	6	4	80	Westinghouse.

Current Fluctuations during Straight Line Acceleration Period. When resistance is cut out of the motor circuit in passing from one controller point to the next, there is a sudden increase in current accompanied by an increase of tractive effort which produces a sudden increase in rate of acceleration. This increase in rate of acceleration is evidenced by a jerk whose violence depends upon the magnitude of current fluctuation, train resistance and inertia and the tractive effort characteristic of the motor. An excessive increase in rate of acceleration may cause discomfort to the passengers, it may produce too great mechanical strains in the trucks, draw bars, gears or links, or the driving wheels may be slipped. The increase in rate of acceleration should not exceed 0.6 mile per hour per second for passenger service. For usual conditions of city service the value of maximum current during the straight line acceleration period may be taken at about 10 per cent. above the average; thus the minimum will be the same amount below the average, making the total current fluctuation about 22 per cent. Smaller fluctuations are used

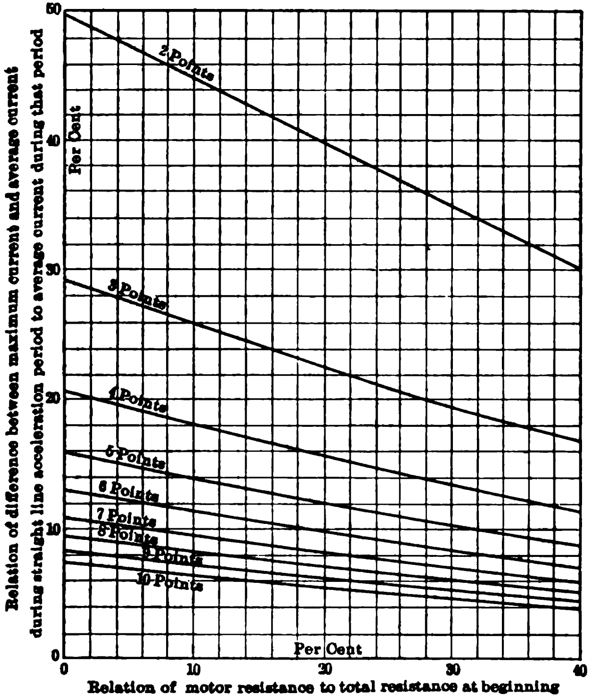


FIG. 19.—Number of series controller points in relation to resistances and current fluctuations.

in heavier service.. In freight locomotive operation the fluctuation of the draw-bar pull should not be greater than 15 per cent. The degree of perfection to which the acceleration of a train is accomplished depends upon the number of steps into which the starting resistance is divided, the proportioning of these steps and the speed and degree of uniformity with which the steps are cut out. The proportioning of the steps demands a study of equipment and conditions. The speed and degree of uniformity with which the steps are cut out are cared for automatically in the case of automatic multiple-unit control, but in the case of hand-operated control, except where auxiliary regulating device is attached to the controller, they depend upon the skill and painstaking efforts of the motorman.

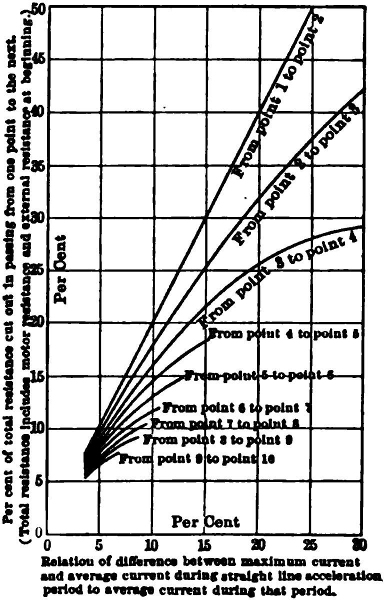


FIG. 20.—Per cent. of resistance between series controller points.

Calculation of Resistances and Resistance Steps for the Control of Direct-current Motors. Following is a method of approximating the resistance steps for the control of direct-current series motors.

Rheostatic Control and Series Portion of Series Parallel Control. Figs. 19 and 20 are for the calculation of both rheostatic control and the control during the series acceleration period of series-parallel control. These curves are based on the assumption that the per cent. increase in counter electromotive force due to increase in current in motor fields is equal to one-half the per cent. increase in this current. This assumption may be made without causing material error in practical results ordinarily required in the calculation of resistance steps for electric railway work. These curves are used in the arrangement of resistance for entire rheostatic control just as they are used in arranging the resistance for the series portion of the series-parallel control; therefore, the explanation of the method of using the curves for the series portion of series-parallel control, as given by the example on p. 348, will also serve to show how the curves are used for entire rheostatic control.

Parallel Portion of Series-parallel Control. Formulas for the approximation of resistance steps in parallel straight line acceleration:

Significance of symbols in the following formulas:

A = counter electromotive force of each motor at completion of series straight line acceleration at instant controller is moved from the last series straight line acceleration point, volts

$b = \frac{B}{C}$

B = motor counter electromotive force

C = motor counter electromotive force at instant controller breaks contact at a point

D = combined counter electromotive force of motors as connected for parallel operation at instant controller makes contact at first parallel point

So long as the motor fields are operating at less than full saturation, B will be greater than C because the current through the fields when the controller makes contact at a point is greater than the current through the fields when the controller breaks contact at the preceding point. The values of b may be taken from the saturation curve for the motor. Where, during straight line acceleration, a commercial motor is operated at an average current approximately equal to that of the 1-hour rating of the motor, the assumption that the per cent. of increase from C to B is equal to half the per cent. of increase of current may be made without causing material error in practical results ordinarily required. Such an assumption permits the following convenient approximate value:

$$b = \left(1 + \frac{N - P}{2P}\right)$$

N = current at instant controller makes contact at any point, amperes

P = current at instant controller breaks contact at point, amperes

Q = current at instant controller breaks contact at last series point, amperes

E = total applied electromotive force, volts

R_1 = total resistance of motors in series connection, external resistance cut out, ohms

n = number of motors in series across total applied electromotive force in series position of controller

R_2 = combined resistance of motors in parallel connection, external resistance cut out, ohms

R_3 = necessary total resistance of circuit at first point in parallel straight line acceleration (including motor resistance), ohms

r_1 = external resistance which must be placed in series with motors at first point in parallel straight line acceleration

$(r_1 - r_2)$, $(r_2 - r_3)$, etc. = resistance which must be cut out in passing from points (1 to 2), (2 to 3), etc., respectively

$$a = \frac{P}{N}$$

$$A = \frac{b(E - R_1P)}{n}$$

$$R_3 = \frac{E}{N}$$

$$r_1 = \frac{E - D}{N} - R_2$$

$$r_1 - r_2 = \frac{Eb}{N}(1 - a) - \frac{D}{N}(1 - ab)$$

$$r_2 - r_3 = ab(r_1 - r_2)$$
$$r_3 - r_4 = ab(r_2 - r_3)$$
$$r_4 - r_5 = ab(r_3 - r_4)$$
$$r_5 - r_6 = ab(r_4 - r_5)$$

Example: Calculation of resistance steps for the series-parallel control of four 60-h.p. 500-volt direct-current series motors having a resistance of 0.42 ohm each. The steps are to be so arranged that the maximum current during straight line acceleration shall not exceed the average current during that period by more than 10 per cent. The average current per motor required during straight line acceleration is 100 amperes.

Resistance of set of four motors arranged for series acceleration, two in series and two in parallel = 0.42 ohm,

total average current = 200 amperes

assuming that the maximum current during straight line acceleration is 10 per cent. greater than the average current;

maximum current during acceleration in series = 220 amperes,

total resistance (including motors) necessary at beginning $= \frac{500}{220} = 2.273$ ohms, relation of motor resistance to total resistance at beginning $= \frac{0.42 \times 100}{2.273} = 18.5$ per cent.

Referring to Fig. 19, the vertical through the "*relation of motor resistance to total resistance at beginning*" of 18.5 per cent. intersects the horizontal through the "*relation of difference between maximum current and average current during straight line acceleration period to average current during that period*" at 10 per cent., on the "6-point" curve. This indicates that the controller should have six points for series acceleration. Now (Fig. 20) following the vertical through the "*relation of difference between maximum current and average current during straight line acceleration period to average current during that period*," 10 per cent., intersections with the curves show that the "*per cent. of total resistance cut out in passing from one point to the next*" should be as given in the second column of the following table:

Interval	Resistance Per cent. of total	Ohms
Point 1 to point 2	20.0	0.45
Point 2 to point 3	18.0	0.41
Point 3 to point 4	16.2	0.37
Point 4 to point 5	14.5	0.33
Point 5 to point 6	13.1	0.30
Resistance of motors	18.5	0.42

Multiplying the total resistance in circuit at beginning, 2.273, by each of these per cents. gives the values in the third column for the number of ohms which should be cut out in passing from point to point.

If, in using Fig. 19, the vertical through 18.5 per cent. and the horizontal through 10 per cent. had not intersected on, or very near, one of the diagonal curves, the value, 10 per cent., for the "relation of difference between maximum current and average current . . . " should be changed by trial to a value at which the corresponding value of the "relation of motor resistance to total resistance at beginning" is such that the horizontal and vertical through these respective points intersect on, or very near, a diagonal.

Parallel Straight Line Acceleration. Assuming, as in the case of series straight line acceleration just considered, that the maximum current during parallel straight line acceleration will exceed the average current during parallel straight line acceleration by 10 per cent.

$$b = \left(1 + \frac{N-P}{2P}\right)$$

$$= \left(1 + \frac{440-360}{720}\right)$$

$$= 1.11$$

$$A = \frac{b(E - R_1Q)}{n}$$

$$= \frac{1.11\,[500-(0.42 \times 180)]}{2}$$

$$= 236 \text{ volts per motor}$$

$$r_1 = \frac{E-D}{N} - R_2$$

$$= \frac{500-236}{440} - 0.105$$

$$= 0.495 \text{ ohm}$$

$$r_1 - r_2 = \frac{Eb}{N}(1-a) - \frac{D}{N}(1-ab)$$

$$= \frac{500 \times 1.11}{440}(1-0.818) - \frac{236}{440}(1 - 0.818 \times 1.11)$$

$$= 0.180 \text{ ohm}$$

$$r_2 - r_3 = ab(r_1 - r_2)$$

$$= 0.91 \times 0.180$$

$$= 0.164 \text{ ohm}$$

$$r_3 - r_4 = ab(r_2 - r_3)$$

$$= 0.91 \times 0.164$$

$$= 0.149 \text{ ohm}$$

$(r_1 - r_2) + (r_2 - r_3) + (r_3 - r_4) = 0.180 + 0.164 + 0.149 = 0.493$ ohm.

which is nearly equal to the value $r_1 = 0.495$ determined above. This indicates that by using a controller having four parallel points and having the parallel steps of resistances $(r_1 - r_2)$,

$(r_2 - r_3)$ and $(r_3 - r_4)$, respectively, calculated above, the maximum value of current during parallel straight line acceleration will be approximately 10 per cent. above the average current during parallel straight line acceleration.

If one more resistance step, namely $(r_4 - r_5)$, had been determined and it was found that $(r_1 - r_2) + (r_2 - r_3) + (r_3 - r_4) + (r_4 - r_5) = r_1$, approximately, this would indicate that a controller having five parallel points should be used. If the value of $(r_1 - r_2) + (r_2 - r_3) +$ etc. differs materially from the value determined, for r_1, then a new calculation should be made starting with another permissible value of per cent. by which the maximum value of current during parallel straight line acceleration exceeds the average current during parallel straight line acceleration.

The energy dissipated in the resistor causes a rise in temperature of the latter. The extent of such rise will depend upon the material, design and radiation conditions of the resistor and the intensity, duration and frequency of application of load upon the resistor. The resistance of the resistor at any instant will depend upon its temperature and material. For cast-iron resistors an increase of at least 10 per cent. above the cold resistance may be expected. The temperature coefficient of resistance of a cast-iron resistor grid is approximately 0.0008 per degree C. The temperature coefficient of resistance of an iron alloy resistor grid is approximately 0.0004 per degree C. It is common practice in the manufacture of resistor grids to allow a variation of the resistance within the limits 5 per cent. above and below the rating.

WESTINGHOUSE 8-IN. CAST-IRON RESISTOR GRIDS

Style	Pattern	Resistance, ohms	Capacity,* amperes
46,029	N 3,357	0.015	100.0
46,030	N 3,215	0.020	86.5
46,032	N 3,214	0.030	70.8
46,033	N 3,315	0.040	67.2
46,034	N 3,213	0.050	54.8
46,035	N 3,354	0.060	50.0
46,036	N 3,212	0.070	46.3
46,037	N 3,353	0.080	43.3
46,083	N 3,211	0.100	38.7

* Continuous capacity for 240 deg. C. rise.

GENERAL ELECTRIC CAST-IRON R.G. GRIDS

Size number of grids	Resistance per grid at 25 deg. C.	Capacity, amperes	
		Continuous at 175 deg. C. rise	Intermittent (10 sec. on; 20 sec. off) at 250 deg. C. rise
1	0.01	80	160
3	0.015	70	140
5	0.022	60	120
7	0.033	50	100
9	0.05	40	80
10	0.05	35	70
12	0.075	30	60

The intermittent current carrying capacity depends upon the particular grid, the service and the length of time the current flows. The grids listed in the above table will safely carry five times their rated continuous current for a period of 30 seconds when starting cold.

Installation of Grid Resistors. Fig. 21 shows a method of installing grid resistors presented by Mr. R. H. Parsons. Fig. 21 represents a set of three-box resistors, suspended with iron hangers from the car floor or framework to which are fastened two wooden hangers covered with asbestos lumber. A sheet of ¼-in. asbestos lumber is placed below the wooden hangers, and the grids are attached under the asbestos by bolts through the wooden hangers. Care should be exercised to allow sufficient space between the grids and between the two outside grids and the iron hangers. The iron hangers should be grounded. The resistors and their conduit connections are shown. It will be noted that the wires are separated as they leave the fiber cover of the condulet and that they touch nothing until they reach the terminal of the grid. As a rubber bushing lines the fiber outlet to the condulet, it is safe from grounds and short circuits.

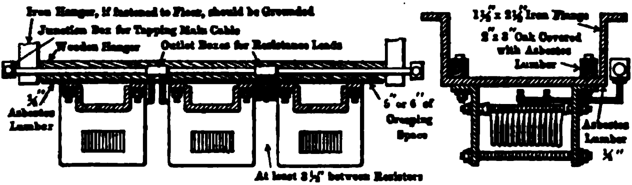

Iron Hanger, if fastened to Floor, should be Grounded
Junction Box for Tapping Main Cable
Wooden Hanger
Outlet Boxes for Resistance Leads
¼"
Asbestos
Lumber
5" or 6" of
Creeping
Space
At least 3½" between Resistors
1½" x 2½" Iron Flange
2" x 3" Oak Covered
with Asbestos
Lumber
Asbestos
Lumber
¼"

FIG. 21.—Installation of grid resistors.

Auxiliary Contactor Equipment. The auxiliary contactor equipment is applied to the hand controller and is arranged to break the power circuit beneath the car rather than within the controller. Figs. 22 and 23 show the connections of this equipment. The controller is provided with an auxiliary contact device at the base of the main cylinder. It consists of two contact fingers which are operated by a pivoted arm and a projection on the fiber disk at the bottom of the cylinder. The fingers are normally held open at the off position by the projection. On turning the controller cylinder, the main operating fingers make contact, and then the projection on the disk disengages, allowing the auxiliary fingers to close. A magnetic blowout is provided in the device to extinguish the arc when the fingers open to the off position. One of these fingers is connected to the operating coils of two standard contactors operating in series, the other through a switch and fuse to trolley. The main circuit after passing through a protective device, such as switch and fuse or circuit-breaker, connects to the contactors, then to the controller and thus to motors. A projection may also be provided on the disk to open the contactors in passing from series to parallel. It will readily be seen that with this arrangement all heavy arcing occurs in the contactors and not in the controller. The two contactors, with resistance tubes which are placed in series with the operating coils, are mounted in a sheet-iron box located under the car. A further development of this system is in using the contactors as circuit-breakers. This is accomplished by the use of an auxiliary circuit-breaker the tripping coil of which is in the trolley circuit, and the contacts in the circuit feeding the contactor coils. This auxiliary circuit-breaker can be set to trip at any predetermined current between certain limits. When the current reaches the predetermined point, the tripping coil pulls in the armature and opens

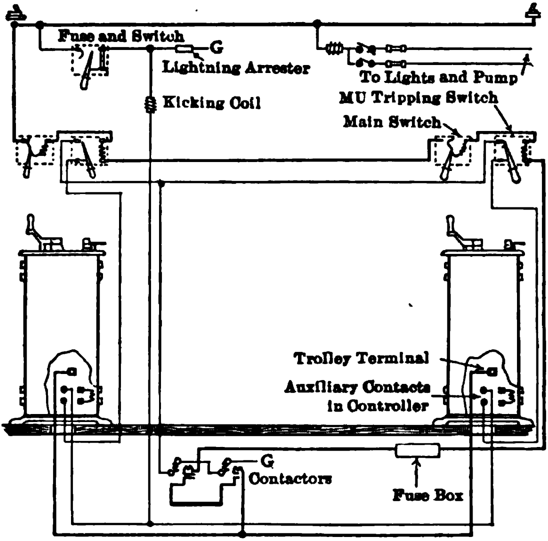


FIG. 22.—Wiring diagram for auxiliary contactor equipment.

the switch, thus breaking the contactor operating circuit and opening the contactors. The switch can also be tripped by throwing the handle to the off position.

Advantages of Power-operated Control. Following are some of the advantages of power-operated control. These are secured with simplicity, reliability and low maintenance cost.

(1) Multiple-unit operation is made practicable. Thus the motive power may be distributed in small units without loss of efficiency and since all the wheels may thus be made driving wheels a maximum tractive effort is made possible. A maximum closeness of speed adjustment is secured and strains on mechanical transmission and draft gear are reduced to a minimum.

(2) All circuit-breakers and other controlling devices which carry main motor current are removed from the platform and placed

beneath the car. This reduces the possibility of danger to passengers and stimulates more careful manipulation of the control. Platform weight and space economy are effected.

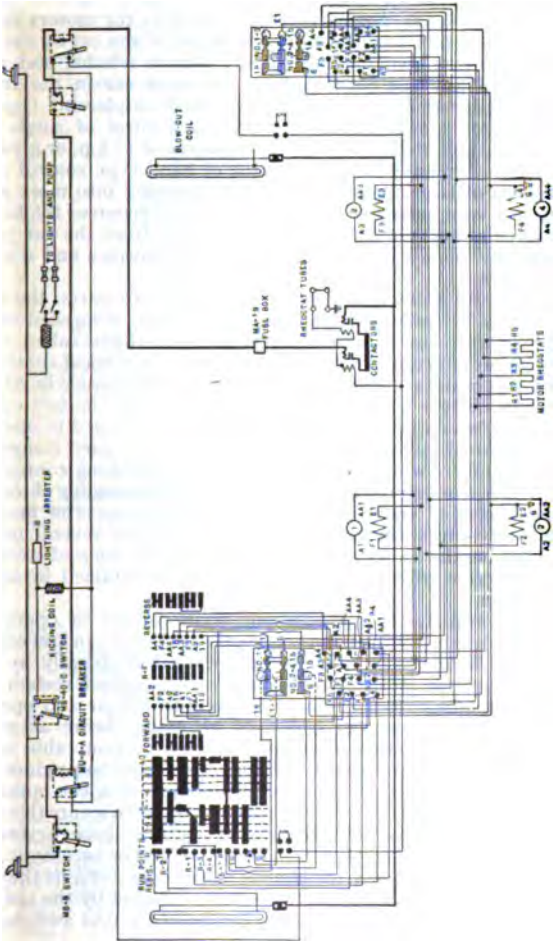


FIG. 23.—Circuits of K-28-F controller with auxiliary contactor.

(3) Switches are operated with heavy contact pressure and reliable overload protection is secured.

Multiple-unit Control

The multiple-unit type of control was brought out primarily for the control of motors in a service requiring that cars be operated singly or several cars coupled together in a train and operated simultaneously. When several cars are coupled together in a train, the train connections are so arranged that the motors on all of the cars may be controlled from either end of any car by a single operator, the cars being coupled in any desired relation and with either end of any car connected to any other car in the train. Although designed for train operation, the multiple-unit type of control is used almost universally for the control of single car equipments where the motors have a capacity of 50 h.p. or greater, owing to the excessive size and weight of hand type control used with motors of large capacity. It is also coming into more general use for equipments of all sizes because it removes the heavy power circuits and circuit-breaking apparatus from the car platform thereby removing a great source of annoyance and danger to passengers.

Train control systems consist in general of two parts, the first consisting of a series-parallel motor controller composed of a number of switches or circuit-breakers, sometimes called contactors, whose function is to effect the different electrical combinations of the motors and regulate the starting resistance in circuit with them. There is also a reverse switch for the motors called the reverser, which is actuated by the same means used to operate the circuit-breakers or contactors. The second part comprises master controllers which operate the motor controlling contactors and reversers through the medium of train wires extending throughout the length of train so operated. A single operator may simultaneously effect similar combinations upon the several motor cars composing the train thus giving to the train the same advantages of large tractive effort and rapid acceleration obtained in single car operation.

The two systems of multiple-unit train control in operation differ in the means employed to actuate the contactors and reversers, the General Electric contactor being operated electrically by the line current, while in the Westinghouse train control system the contactor or unit switch is closed by compressed air and opened by a powerful spring, the necessary air-valves being actuated electrically by the master controller through a train cable using storage battery or line current. Each system aims to produce the same result, that is, duplicate the performance of a car operated singly, but the systems differ in the means adopted to secure this end.

Multiple-unit control is divided into two general classes according to the method of acceleration, *i.e.*, hand-operated or automatic, the former being wholly under the control of the operator as is the case with the hand controller while the latter is effected by the current limiting relays and interlocks on the contactors or unit switches.

General Electric Multiple-unit Control

Hand-operated Acceleration. The multiple-unit system of control with hand-operated acceleration is in general use both for train and single car operation. It is in effect the same as the hand-operated cylinder type of control except that instead of combining

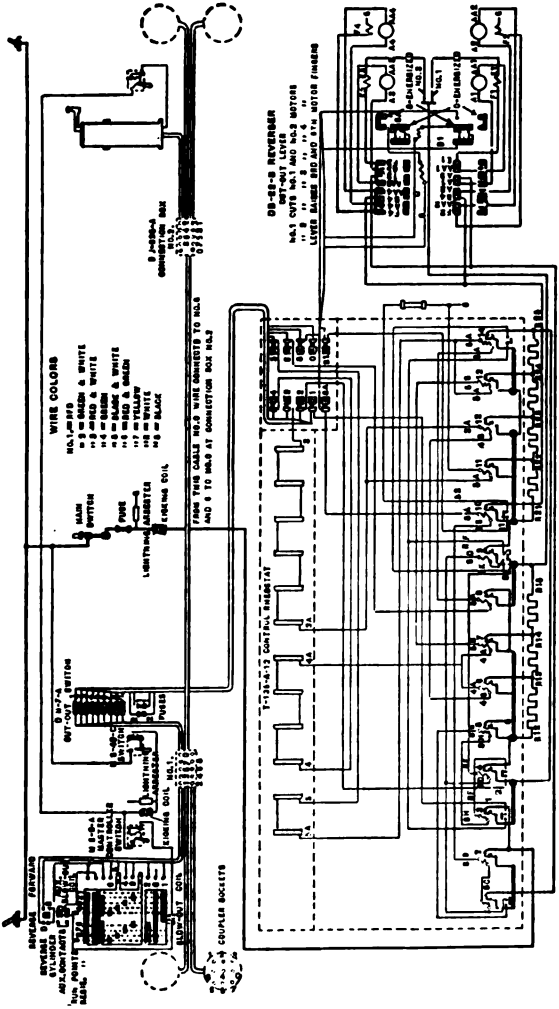


FIG. 24.—Circuits of S.G.E. hand-operated control.

all the various circuit-breaking contacts upon a single cylinder operated by hand, it divides each contact into a separate circuit-breaker, or contactor, and actuates these electrically through train wires by means of a small master controller. The motor-control, therefore, comprises those parts which handle motor current, all of these parts being electrically operated and located underneath the car. The master control comprises those parts which handle the control current for operating the motor-control apparatus, the master controller being operated by hand and located in the vestibule at either end of the car. The motor-control is local to each car and current for this circuit is taken directly from the trolley or third rail through the circuit-breakers or contactors, starting resistance and reverser to the motors and thence to the ground. Where it is necessary to operate with a gap in a third rail system it is sometimes customary to install a train line so that any car may supply the motor current for the other cars in the train. Train wires made continuous by means of jumpers between cars extend throughout the train.

On each car the operating coils of the motor-control are connected to this train line through a cut-out switch, these train wires being energized in proper sequence by the hand-operated master controller on the platform. Current for the master control is taken directly from the trolley or third rail, through the master controller which is being operated by the motorman, to the train line and thus to the operating coils of the contactors forming the motor-control on all cars in the train.

Master Controller. The master controller is similar in design to the original cylinder controller in that it contains a movable cylinder and stationary contact fingers are used to supply current in proper sequence to the different wires of the train line for energizing the operating coils of the motor-control. The value of current required is very small, not exceeding 2.5 amperes for each car in the train. The master controller is provided with two handles, one for operating and one for reversing the direction of the train movement.

The *operating handle* is provided with a button which must be kept down except when the handle of the controller is in the off position, as releasing this button permits an auxiliary circuit to open, cutting off the supply of current in the master controller, thus de-energizing the train line and opening up the motor-control apparatus. This button is intended to serve as a safety appliance in case of physical failure of the motorman.

The *reverser handle* is connected to a separate cylinder which establishes control connections for throwing the electrically operated reverser either forward or reverse position when the master-controller handle is on the first or off point. The operating circuit for the reverser is so interlocked that unless the reverser itself corresponds to the direction of the movement indicated by the reverser handle of the master controller, the line contactors on that car cannot be energized.

Transition. In train control bridging connections (see page 333) are used in changing from series to parallel connection.

Control Coupler. Couplers between cars are so designed as to give a corresponding connection of train wires, this being secured by means of proper mechanical design of plug and sockets, it being impossible to improperly insert the plug in the sockets.

Contactor. The contactor is a switch operated by solenoid coils, and each contactor may be considered as the equivalent of a finger and its corresponding cylinder segment in the hand-operated K type controller. It consists of an iron magnet frame with an operating coil and two main contacts, one fixed and the other directly connected to the movable finger. These main contacts open and close in a molded insulation arc chute provided with a magnetic blowout. Interlocks are provided for making the necessary connections in control circuits to ensure proper sequence in operating the different contactors. All of the contactors are mounted in a box placed on a wooden insulating support beneath the car, this box being provided with a sheet iron cover lined with insulating material.

Reverser. The reverser is a switch, the movable part of which is a rocker arm operated by two electromagnets working in opposition. The coils receive their energy from the master controller through the train line, and the connections are such that only one coil can be operated at a time. Leads from the motors are connected to the main reverser fingers and by means of copper bars on the rocker arm, the proper relations of armature and field windings are established for obtaining forward or backward motion of the car.

Sprague General Electric Automatic Multiple-unit Control provides for the acceleration of the train at a predetermined current in the motor, this feature being provided without preventing the manual operation of the master controller at less than the predetermined current if desired. The operation of the contactors is controlled from the master controller, but governed by a notching or current limit relay in the motor circuit, so that the accelerating current of the motors is substantially constant. This is accomplished by having small auxiliary interlocking switches on certain of the contactors, the movement of each connecting the operating coil of the succeeding contactor to the control circuit. The contactors are energized under all conditions in a definite succession, starting with the motors in series with all resistance in circuit; the resistance cut out step by step; the motors then connected in parallel with all resistance in, and the resistance again cut out step by step. The progression can be arrested at any point, however, by the master controller and is never beyond the point indicated thereby. The rate of the progression is governed by the current limit relay so that the advance is not made faster than will keep the current in the motors within the prescribed limit. One of these relays is provided with each car equipment so that while the contactors on each car of a train are controlled from the master controller in use for the application and removal of power, the rate of progression through the successive steps is limited by the relay on each car independently, according to the adjustment and current requirements of that particular car. Another automatic protection for individual cars is provided by a second or potential relay having its coil connected to the lead from the collecting shoes of the respective car and its contacts so connected breaker, or contactor, and actuates these electrically through train wires by means of a small master controller. The motor-control, therefore, comprises those parts which handle motor current, all of these parts being electrically operated and located underneath the car. The master control comprises those parts which handle the control current for operating the motor-control apparatus, the master controller being operated by hand and located in the vestibule at either end of the car. The motor-control is local to each car and current for this circuit is taken directly from the trolley or third rail through the circuit-breakers or contactors, starting resistance and reverser to the motors and thence to the ground. Where it is necessary to operate with a gap in a third rail system it is sometimes customary to install a train line so that any car may supply the motor current for the other cars in the train. Train wires made continuous by means of jumpers between cars extend throughout the train.

On each car the operating coils of the motor-control are connected to this train line through a cut-out switch, these train wires being energized in proper sequence by the hand-operated master controller on the platform. Current for the master control is taken directly from the trolley or third rail, through the master controller which is being operated by the motorman, to the train line and thus to the operating coils of the contactors forming the motor-control on all cars in the train.

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The *operating handle* is provided with a button which must be kept down except when the handle of the controller is in the off position, as releasing this button permits an auxiliary circuit to open, cutting off the supply of current in the master controller, thus de-energizing the train line and opening up the motor-control apparatus. This button is intended to serve as a safety appliance in case of physical failure of the motorman.

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Transition. In train control bridging connections (see page 333) are used in changing from series to parallel connection.

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Reverser. The reverser is a switch, the movable part of which is a rocker arm operated by two electromagnets working in opposition. The coils receive their energy from the master controller through the train line, and the connections are such that only one coil can be operated at a time. Leads from the motors are connected to the main reverser fingers and by means of copper bars on the rocker arm, the proper relations of armature and field windings are established for obtaining forward or backward motion of the car.

Sprague General Electric Automatic Multiple-unit Control provides for the acceleration of the train at a predetermined current in the motor, this feature being provided without preventing the manual operation of the master controller at less than the predetermined current if desired. The operation of the contactors is controlled from the master controller, but governed by a notching or current limit relay in the motor circuit, so that the accelerating current of the motors is substantially constant. This is accomplished by having small auxiliary interlocking switches on certain of the contactors, the movement of each connecting the operating coil of the succeeding contactor to the control circuit. The contactors are energized under all conditions in a definite succession, starting with the motors in series with all resistance in circuit; the resistance cut out step by step; the motors then connected in parallel with all resistance in, and the resistance again cut out step by step. The progression can be arrested at any point, however, by the master controller and is never beyond the point indicated thereby. The rate of the progression is governed by the current limit relay so that the advance is not made faster than will keep the current in the motors within the prescribed limit. One of these relays is provided with each car equipment so that while the contactors on each car of a train are controlled from the master controller in use for the application and removal of power, the rate of progression through the successive steps is limited by the relay on each car independently, according to the adjustment and current requirements of that particular car. Another automatic protection for individual cars is provided by a second or potential relay having its coil connected to the lead from the collecting shoes of the respective car and its contacts so connected in the contactor circuits that in case of failure of power to any car, such as would be caused by passing over a dead section of rail, this relay is de-energized and causes the control circuits on that car to be thrown back to series position with resistance in, and when power is restored the control progresses step by step to its former advanced position. This prevents any surging or overloading in such contingencies. There are five circuits leading from the master controller and five corresponding train wires. The five circuits

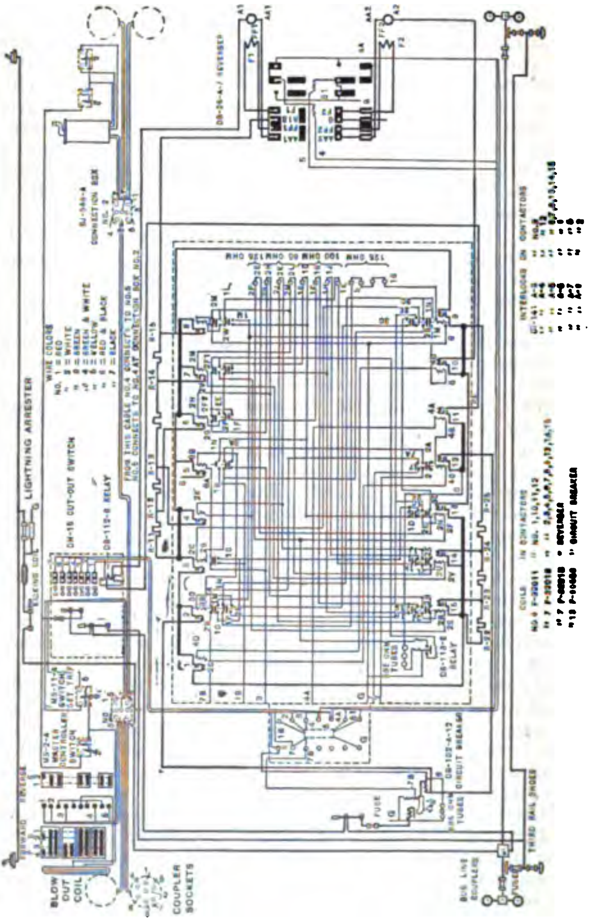


FIG. 25.—Circuits of S.G.E. automatic control.

comprise one for forward direction, one for reverse, one each for series and parallel, and the fifth for controlling the acceleration. When the master controller is moved to its first forward point, the No. 4 direction wire is energized. This throws the reverser to its forward position, if it is not already so thrown. The reverser is electrically interlocked so that it cannot be thrown when the motors are taking current. The operating current is so arranged that unless the reverser is thrown for the direction of car movement indicated by the master controller handle, the contactors and motors on that particular car are inoperative. When the reverser has moved to the proper position, connections are made by it from the direction wire through the forward reverser operating coil and the coils of the contactors which control the main or trolley leads to the motors. At the same time the series-contactor is energized by means of a second train wire and the circuit through the motors in series is completed with all resistance in circuit, giving a slow speed forward. In this position no further action is produced.

When the master controller is moved to its second forward position, circuit is completed through the accelerating wire (No. 1), in addition to the above circuits which energizes the contactor shunting the first resistance step, and current also passes through the fine wire coil and the contacts of the current limit relay. The plunger in this relay has a lost motion, so that an appreciable time is required to move it, and this time is made the same as that required by the contactor in closing its contact. These two devices thus operate simultaneously. The contactor being lifted, shifts its operating coil by means of the interlocking switches into the circuit through the series-contactor above mentioned, which maintains it in the closed position independent of the circuit that has lifted it. At the same time the relay has opened the lifting or actuating circuit. The shunting of the resistance step by the contactor causes an increased current to flow through the motor circuit and through the heavy coil of the relay, which is sufficient to hold the relay plunger in its raised position and so keep the actuating circuit open until the motors, by speeding up, cause the current to diminish enough to allow the relay plunger to drop and again close the accelerating circuit. Circuit is now established through the contactors shunting the second resistance step, and these contactors are energized and the relay again lifted and held up by the increased current and so on until all the resistance is cut out.

When the master controller is moved to the third position the parallel circuit is established, the bridge-contactor and then the parallel contactors closed and the motors connected in the multiple arrangement. When the master controller is moved to its fourth or full-on position, the resistance is cut out step by step as in series.

These same successive actions are produced if the master controller is thrown to the full-on position directly, as the interlocking contacts prevent an advance circuit being established before the proper preliminary action has taken place.

If at any point during the acceleration, the master controller is moved to its lap position, the existing position of the contactors is maintained, but the further progression is arrested so that th motorman can limit the acceleration to as slow a rate as desired, but he cannot exceed the predetermined rate for which the relay is adjusted.

A control cut-out switch is provided in each car so that in an emergency the operating coils of the contactors, reverser and circuit-breaker on a particular car may be disconnected from the control circuit.

It is necessary to positively energize two distinct train wires in order to operate the contactors required for starting the motors.

Three separate contactors with their main contacts in series are used for completing and breaking each motor unit.

Several small fuses are provided in the control circuit for effectively protecting the control apparatus.

Should the train break in two, the control current is automatically and instantly cut off from the detached rear portion without effecting the ability of the motorman to control the front part of the train.

Control for 1200-volt motors comprises essentially the same arrangement of apparatus as described for 600-volt motors. Asmost of such equipments must operate over tracks equipped with 600-volt trolley in cities, the motors are wound for 900 volts and connected permanently two in series. With 1200 volts there is the possibility of a single motor receiving practically full trolley potential if its wheels should slip, hence the method used of winding each motor for 900 volts with sufficient margin in its commutating constants to allow momentary impressed 1200 volts. The motors being connected two in series for 1200-volt operation permits operation with all motors in multiple with 600 volts trolley potential, thus giving same speed of car at 600 and 1200 volts. Such parallel motor connection is seldom resorted to however as there seldom exists the necessity of providing equal maximum speeds on 1200- and 600-volt trolley sections. Keeping two motors permanently connected in series gives about half speed for city running and this relation to the interurban speeds is about right. The secondary control system and master controller are the same as with standard 600-volt motors. On 1200-volt trolley sections the car lamps and master control system are energized by a dynamotor located beneath the car and made self starting like an air compressor motor. The air compressor motor operates from the 1200-volt trolley as does the car heating system. The only difference in 1200- and 600-volt train control systems lies therefore in the introduction of the dynamotor, and the operation is the same as described for 600-volt equipments.

Operation of S.G.E. Automatic Control. The following is from a paper by Mr. F. E. Case, Proceedings A.E.R.E.A., 1908. (References are to Fig. 26.)

First Forward Position of Controller. With the master controller on first position forward, current flows from *T* through wire 4 to reverser coil through 5*A* to ground *G*. This throws the reverser to the proper position, if it has not been left there by previous operation. The reverser in throwing over connects wire 4 by 5*B* through coils *L*1 and *L*2 to ground. Current also flows through wires 2*A*, 2*B* and 2*C* to coil *S* and wires 2*D*, 2*E*, 2*F*, 2*G* and 2*H* to ground. The small double circles in the circuit represent resistances which have an approximate value equal to that of the contactor coil. These circuits operate the necessary contactors for connecting the motors in series with all the starting resistance in. The line relay is closed as it is connected across the motors.

Second Forward Position. When the master controller is moved to the second position, the control current flows through wire 1, current limit relay, wires 1*A*, 1*B*, 1*C*, coil *RR*4 to 2*E*, etc., to ground. The *RR*4 contactor and relay close simultaneously. As the contactor closes, the contact between 2*K* and 1*C* wires is made previous to the contact between 2*D* and 2*E* being broken, and also just before the relay contact is opened. The circuit through coil *S* then passes from wire 2*D* through 2*J*, 2*K*, 1*C*, coil *RR*4, 2*E*, etc., to ground. The motor current flowing through the heavy coil of the relay being increased by closing *RR*4 is sufficient to hold the relay plunger, just lifted by No. 1 wire circuit and keep its contacts open. After the motor current has dropped a predetermined amount, due to increase of motor speed, the relay plunger drops and the control circuit contacts are again closed. Current then flows through wires 1*A*, 1*B*, 1*D*, 1*E*, coil *R*-1, 2*F*, etc., to ground. This closes *R*-1 contactor and its interlocks shift the coil into the circuit from 2*E*, placing it in series with *S* and *RR*-4 and the relay repeats its previous performance. On the next two steps the *R*-2, *RR*-2, *R*-3, *RR*-3 coils are energized in the same manner. When *R*-4 contactor closes on the last step, the control current flows through wires 1*B*, 1*D*, 1*L*, 1*M*, coil *B* to *G*. The 2*C* wire is opened when contactor *B* closes and contactor *S* and the resistance contactors are permitted to open. The "bridge" contactor *B* is kept closed by the current passing through the 2*B* and 1*M* wires.

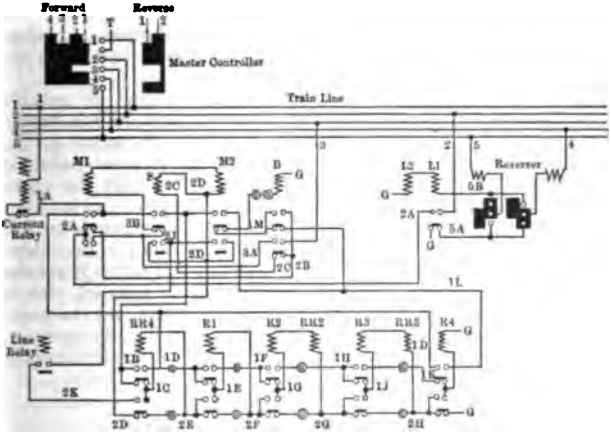


FIG. 26.—Control circuit connections, S.G.E. automatic control.

Third Forward Position. In the third position of the master controller an additional circuit is made through wires 3, 3*A*, 3*B*, coils *M*-1 and *M*-2, wires 2*B*, 2*E*, etc., to ground. When closing *M*-2 contactor opens the circuit of the "bridge" contactor *B* and *M*-1 contactor closes the circuit from 2-*A* to 3*B*, thereby keeping *M*-1 and *M*-2 contactors closed. The motors are now connected in parallel with full resistance in circuit.

Fourth Forward Position. In the fourth position of the master controller current flows through wire 1 and the current relay and the resistance contactors are operated in the same manner as in series, but not in the same order. Current flows through 1*A*, 1*D* and 1*E*, coil *R*-1, wire 2*F*, etc., to *G*, thereby operating *R*-1 contactor first in parallel. After *R*-1 contactor has operated, *R*-2, *RR*-2, *R*-3, *RR*-3 and *R*-4 are closed in the order given. After *R*-4 contactor has closed, the current passes through 1*D* wire through 1*L*, 1*B* and 1*C*, coil *RR*-4, 2*E*, 1*E*, coil *R*-1, etc., to ground and *RR*-4 contactor is, therefore, the last one to close.

Operation at Reduced Rate. When it is desired to notch up slower than the normal rate the master controller handle is brought to the first point and the car slowly started. To secure a slight increase in speed the handle is turned to the second point and returned quickly to the first. This operation will lift the current limit relay and the contactor for the second step, but, as it cuts off the lifting circuit, no more contactors will be closed until the movement is repeated. This method of operation can be followed until all resistance contactors are closed and full series is reached. If desired to cut out the resistance slowly in parallel, also, the controller handle is then brought to the third point and the motors will be connected in parallel with all resistance in. By turning to the fourth point and back quickly to the third, a similar operation to that in series will result.

Westinghouse Multiple-unit Control

Classification According to Source of Current Supply for Valve Magnets. In the Westinghouse multiple-unit control the two classes (automatic acceleration and hand-operated acceleration) each may be again divided according to the source of current supply for the valve magnets. That is, the source of this current may be the line or a storage battery.

Hand-controlled Acceleration Current for Control Circuits Taken from Line. The system of multiple-unit control having hand-controlled acceleration and taking current for the control circuits from the line is the simplest type and is in most general use on interurban and city surface lines for both train and single car operation. It is known as type HL. It is in effect the same as the hand-operated drum type of control, except that instead of combining all the various circuit-breaking contacts upon a single drum, operated by hand, it divides these contacts into separate contactors and actuates these by means of compressed air taken from the air-brake reservoirs and controlled by magnet valves and train lines wires from a small master controller.

This system is made up of two general parts, namely, the auxiliary control system and the motor control system.

Auxiliary Control System. The auxiliary control system comprises a set of train wires, a control resistance, electrically operated valves operating the pneumatic unit switches, a master controller and auxiliary protective devices. Current for the control circuits is taken directly from the trolley or third rail through the master controller to the control resistance, the latter being arranged with low voltage taps for the valve magnet circuits.

Master Controller. The master controller is similar in design to the original drum controller in that it contains a movable cylinder and stationary contact fingers are used to supply current in proper sequence to the different wires of the train line for energizing the operating coils of the motor control. The value of the current required is very small, not exceeding 2 amperes for each car in the train. The master controller is provided with two handles, one for operating and one for reversing the direction of train movement.

Reverse Handle. The reverse handle of the master controller is connected to a separate drum which establishes control connections for throwing the electro-pneumatically operated reverser to either the forward or reverse position when the main master controller handle is moved to the first accelerating notch. The control circuits of the reverser are so interlocked that unless the reverser itself corresponds to the direction of the movement indicated by the position of the reverse handle of the master controller, the unit switches on that car cannot be energized.

Control Coupler. Train line jumpers between cars are so designed as to give a corresponding connection of train wires, this being secured by proper mechanical design of receptacles and jumper heads so that it is impossible to improperly insert the jumper in the receptacle.

Contactors or "Unit Switches." These are placed in a group, being assembled on a common frame and placed in a box beneath the car. The unit switch constitutes a circuit-breaker having a fixed and movable contact and provided with a magnetic blowout, the movable finger being actuated by an air cylinder energized from the brake reservoir and controlled by a magnet valve connected electrically to the train wire system. The switch finger is normally held open by a spring, which is compressed on closing the switch by reason of the greater force of the compressed air at 70 lb. pressure or more. The high pressure used in closing the switch is also made use of to reduce the contact resistance, hence reducing the heating and the size of the switch contacts.

Reverser. The reverse switch or reverser consists of an insulated drum carrying two sets of contacts arranged to make contact with stationary fingers when operated forward and backward by a pair of pneumatically operated pistons actuated through electrically operated valves by the auxiliary or master controller. No magnetic blowout is required as the reverser does not operate when carrying current on account of a mechanical interlocking between the main and reverse drums of the master controller. This reverser switch is enclosed in a sheet-iron box placed beneath the car.

Overload Trip. An overload trip is mounted on one end of the box containing the unit switches. It is actuated by the magnetic

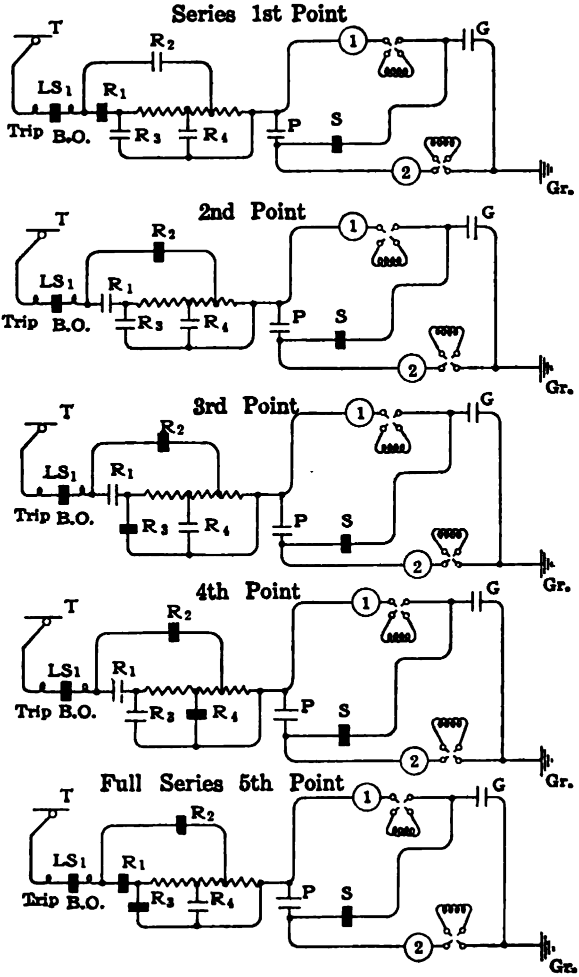


Fig. 27.—Sequence of connections, Westinghouse H. L. control (continued on opposite page).

blowout coil at that end of the group of switches and arranged to open the control circuits of several switches ahead of the motors and main circuit resistance when an excessive overload on the motors occurs.

Control and Reset Switch. The control and reset switch is a small single-pole double-throw canopy switch used for disconnecting

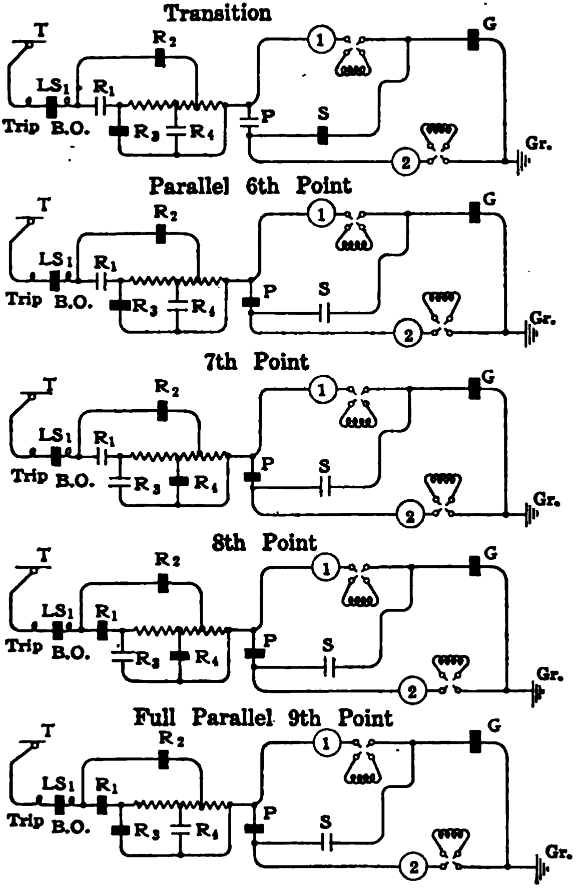
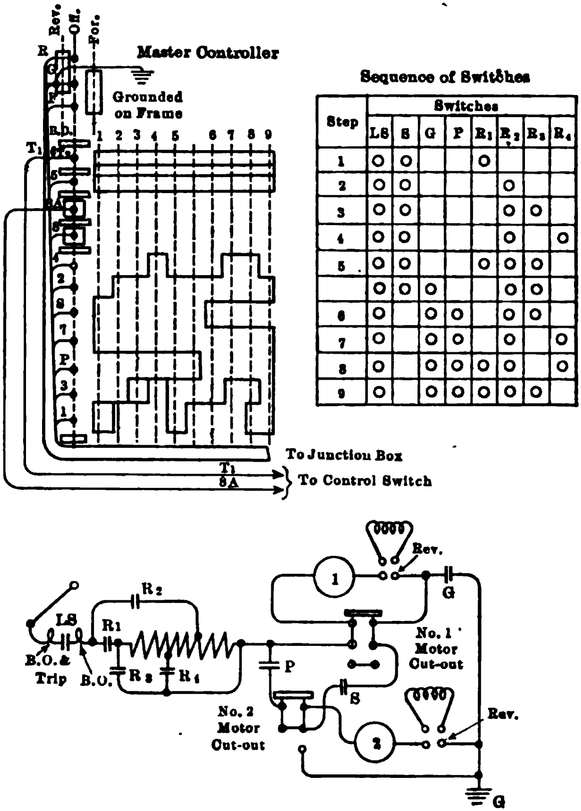


FIG. 27 (Continued).—Sequence of connections, Westinghouse HL control.

the control circuits from the line and closing the control circuit to the reset coil of the overload trip, which can thus be reset from the car platform.

Motor Cut-out Switches. The motor cut-out switches consist of knife switches arranged in a manner similar to those on a hand or drum controller and are mounted in a weather-proof box on one end of the switch group.

Control Resistance. The control resistance consists of a number of flattened tubes wound with resistance ribbon and supported in an iron-clad frame with all live parts protected from the weather. The several tubes are connected in series for the full trolley voltage and low voltage taps are taken off for the magnet valve circuits.

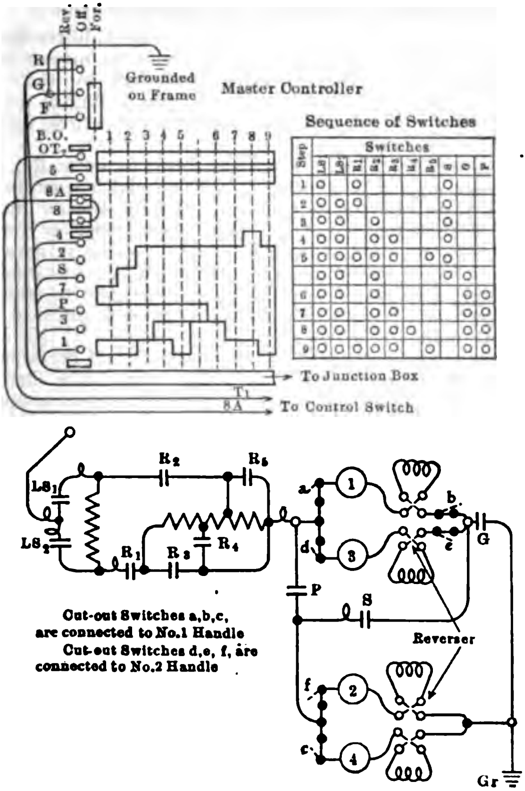


Sequence of Switches

Step	Switches							
	LS	S	G	P	R_1	R_2	R_3	R_4
1	O	O			O			
2	O	O				O		
3	O	O				O	O	
4	O	O				O		O
5	O	O			O	O	O	
	O	O	O			O	O	
6	O		O	O		O	O	
7	O		O	O		O		O
8	O		O	O	O	O		O
9	O		O	O	O	O	O	

FIG. 28.—Scheme of circuits, Westinghouse hand-operated multiple-unit control, line current operation, two motors.

Fig. 27 shows the *sequence of connections* for HL control, giving the sequence of the closing of the contactors and illustrating a method of arranging the main circuit resistance by which five resistance steps are secured by the use of four contactors. Fig. 28 shows the main and control circuits for a double equipment of 60-h.p. motors with HL control, using an eight-switch group. Fig. 29 gives the wiring for an equipment of four 90-h.p. motors



Sequence of Switches

Step	Switches									
	LS1	LS2	R1	R2	R3	R4	R5	S	G	P
1	○		○					○		
2	○	○	○					○		
3	○	○		○				○		
4	○	○		○	○			○		
5	○	○	○	○	○		○	○		
	○	○		○				○	○	
6	○	○		○					○	○
7	○	○		○	○				○	○
8	○	○		○	○	○			○	○
9	○	○	○	○	○		○		○	○

Cut-out Switches a,b,c, are connected to No.1 Handle
Cut-out Switches d,e, f, are connected to No.2 Handle

FIG. 29.—Scheme of circuits, Westinghouse hand-operated multiple-unit control, line current operation, four motors.

Two of the contactors are provided with extra long arcing boxes and are used as circuit-breakers. These are mounted in a separate box together with the overload trip, which opens them in case of an overload or a ground on the motor circuits.

Long experience has indicated that the current-carrying capacity, reliability and low maintenance of the multiple-unit type of controller is due to the very high pressures obtained at the current-carrying contacts. The pressure on the contact is many times greater than in an ordinary drum controller.

Westinghouse Automatic Multiple-unit Control

Westinghouse automatic multiple-unit control differs from the hand-operated type in that the acceleration of the motors is made on a predetermined current which is governed by the control interlocks on the various contactors and the setting of a current limit switch in the motor circuits, instead of being entirely under the control of the operator.

Master Controller. The master controller is normally in the central position and completes a circuit which energizes the emergency train brake magnet valve, releasing the air from the train pipe and setting the brakes. Whenever the master controller handle is returned to the central position, which it does automatically if the operator's hand be removed, it open-circuits the current supply and sets the brakes, bringing the train to rest, hence constituting a safety device to take care of possible physical failure of the motorman.

The master controller has only four notches and the scheme of operation consists of the following progression: The first notch is a coasting position of the controller, as this position opens all motor switches but does not apply the air brakes.

The second notch or switching position establishes connection with the train line so that the reversing switch is closed and the unit switch group closes the circuit to the motors with all resistance in.

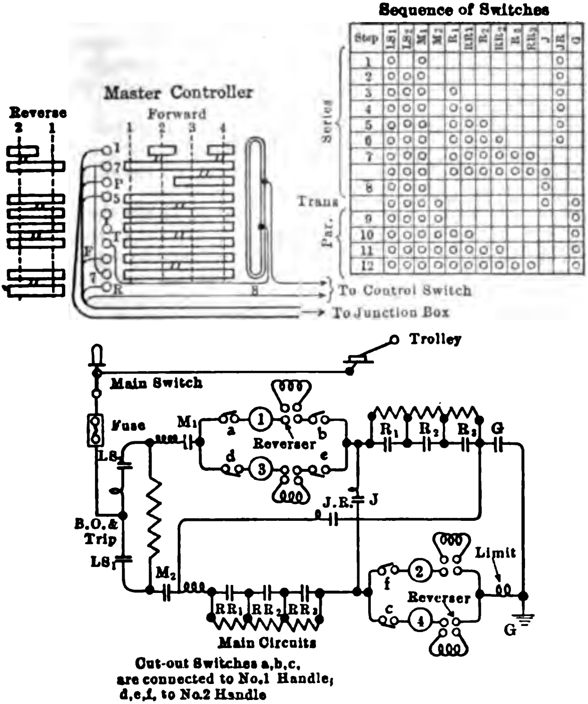
The third notch or full series position of the master controller handle introduces the current limiting relay which permits the progressive picking up of the several unit switches as the current falls below a predetermined value. With the controller handle upon the third notch no further progression is made after the current relay has permitted the closing of the proper unit switches to effect full series position connection of the motors with starting resistance entirely cut out.

The fourth notch on the master controller corresponds to multiple connection and advancing to this position establishes multiple connection of the motors and again brings the current relay into activity, permitting the progressive cutting out of multiple starting resistance until full multiple operation with full-line voltage upon the motors is attained.

Moving the master controller handle to similar notches on the opposite side of the center notch will effect the same combinations, but with the train operating the opposite direction.

Unit Switches. The group of contactors is similar to that used in the hand-operated type of multiple-unit control with the addition of interlocks mounted on the contactors. These consist of copper contacts sliding on spring contact fingers, which are electrically connected to the magnet valves in such a manner that the closing of one energizes the valve magnet of the switch next succeeding, thus producing an automatic progressive action, providing for uniform acceleration with practically constant motor current.

Series Limit Relay or Limit Switch. The series limit relay or limit switch regulates the feeding of the control current to the magnet coils of the accelerating unit switches. It consists of a magnet coil connected in series with the motors and in which operates a plunger terminating in a disk which closes the control circuit to the magnet coils whenever the motor current falls below a predetermined value. This switch used in connection with the control interlock switches of the contactor group, permits the progressive cutting out of starting resistance.



Sequence of Switches

	Step	LS1	LS2	M1	M2	R1	RR1	R2	RR2	R3	RR3	J	JR	G
Series	1	O		O									O	
	2	O	O	O									O	
	3	O	O	O		O							O	
	4	O	O	O		O	O						O	
	5	O	O	O		O	O	O					O	
	6	O	O	O		O	O	O	O				O	
	7	O	O	O		O	O	O	O	O	O			
		O	O	O		O	O	O	O	O	O	O		
	8	O	O	O								O		
Trans		O	O	O	O							O		O
Par.	9	O	O	O	O									O
	10	O	O	O	O	O	O							O
	11	O	O	O	O	O	O	O	O					O
	12	O	O	O	O	O	O	O	O	O	O			O

Main Circuits

Out-out Switches a,b,c, are connected to No.1 Handle, d,e,f, to No.2 Handle

FIG. 30.—Scheme of circuits, Westinghouse automatic multiple-unit control,, line current operation, four motors.

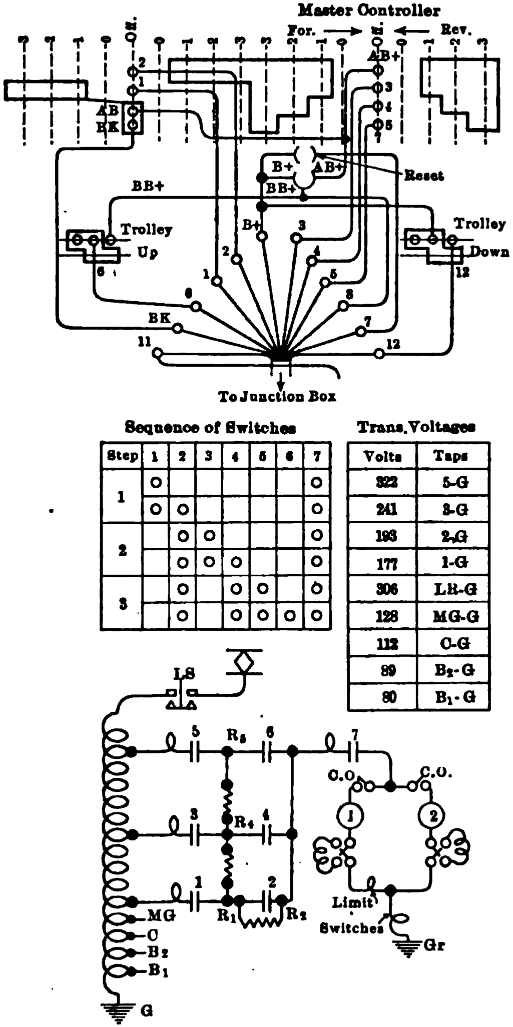
Line Relay. The line relay consists of a coil connected between the line and the ground and provided with a plunger, to which is attached a contact disk. When the line voltage is available, the coil of the line relay is energized, lifting the plunger and causing the contact disk to close a circuit across a pair of contacts. These contacts are directly in series with the auxiliary control circuit of certain contactors, and hence, if the line current fails for any cause, this auxiliary contact is opened, thus opening the main power circuits. Should the line switch be opened or should the current be cut off from the line for any reason, the plunger of the line relays drops, the auxiliary control circuit is opened and all the contactors are opened. This arrangement prevents the motors being held across the line subject to damage should the line current be suddenly resumed after the train has lost its speed. When the contactors are opened by the temporary cutting off of the control current for any reason when the master controller handle is partially or wholly notched up, the limit relay governs the progressive reclosing of these switches.

Fig. 30 shows the main and control circuit connections for a quadruple equipment of 600-volt 75-h.p. motors arranged for automatic acceleration with line current on auxiliary control circuits. This is known as the type AL.

Battery Control. Battery control may be either the hand-operated or automatic type. The former is known as type HB and the latter as type AB. When a battery is used to supply the auxiliary control current for multiple unit control, the control resistance is replaced by a storage battery, supplying current at from 14 to 32 volts. On account of the low voltage used, a plug switch replaces the canopy type control and reset switch used on line current control equipments and the insulation of the entire auxiliary control circuit can be greatly reduced. Battery current for the auxiliary control circuits is particularly adaptable to high voltage systems, either alternating current or direct current, on account of the elimination of the high voltage from the master controller. This type of control is also advantageously employed on elevated and subway systems, and in trunk line service, where close headway between trains is essential. The use of a low voltage control which is independent of the line voltage eliminates various causes for incorrect operation, making this type of control particularly applicable for this class of service. The storage battery used for the control can also be used for emergency lighting, as well as for signal and brake systems. In large systems, where storage batteries can be economically maintained, the benefits of a low voltage control system are most evident. Unless it is desired to charge the storage battery from an outside source at the end of a run, it can be automatically charged from the line on a direct-current system or by a small motor-generator set on an alternating-current system, the amount of charge being regulated by means of an adjustable battery charging resistance and a battery charging relay.

Fig. 31 shows the main and control circuit connection for a double equipment of 175-h.p. single-phase alternating-current motors and type AB control for operation on a system employing 11,000 volts on the trolley.

Control for 1200-volt and 1500-volt Direct-current Motors consists of essentially the same as that used for 600-volt motors.



Sequence of Switches

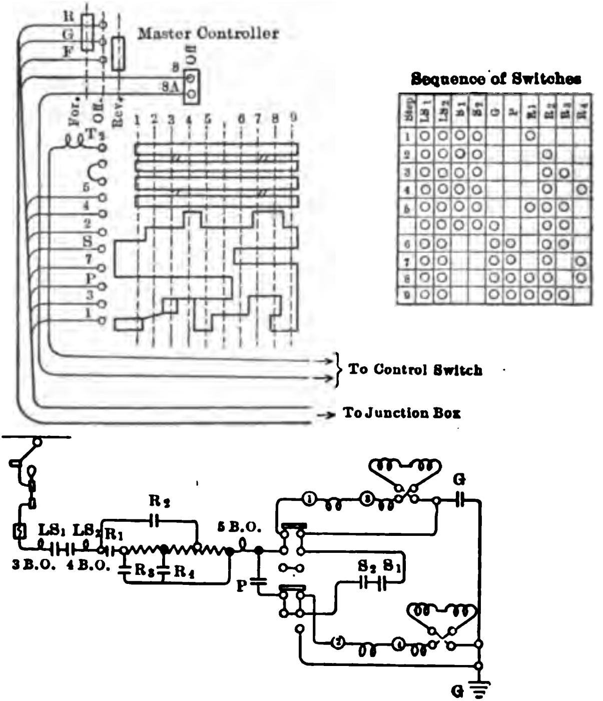
Step	1	2	3	4	5	6	7
1	O						O
	O	O					O
2		O	O				O
		O	O	O			O
3		O		O	O		O
		O		O	O	O	O

Trans. Voltages

Volts	Taps
322	5-G
241	3-G
193	2-G
177	1-G
306	LR-G
128	MG-G
112	C-G
89	B_2-G
80	B_1-G

FIG. 31.—Scheme of circuits for Westinghouse automatic multiple-unit control, battery current operation, two alternating-current motors.

Since most of these equipments must operate on 600-volt trolley through cities, the motors are wound for an impressed voltage of 600 or 750 volts and connected two in series. The contactors in the motor control circuit are arranged to give twice as many breaks in series when opening the motor circuit as are secured on 600-volt control, thus dividing up the arcs and greatly reducing wear on switch contacts. When 1200-volt motors are operated on 600-volt trolley for a considerable proportion of the time, it is desirable to add a series-parallel switch to the equipment for changing the motor connections so as to give full speed on half normal line voltage. Where half normal speed is sufficient when operating on 600 volts, the motors are left permanently connected in series.



Sequence of Switches

Step	LS1	LS2	S1	S2	G	P	R1	R2	R3	R4
1	○	○	○	○			○			
2	○	○	○	○				○		
3	○	○	○	○				○	○	
4	○	○	○	○				○		○
5	○	○	○	○			○	○	○	
	○	○	○	○	○			○	○	
6	○	○			○	○		○	○	
7	○	○			○	○		○		○
8	○	○			○	○	○	○		○
9	○	○			○	○	○	○	○	

FIG. 32.—Scheme of circuits, Westinghouse hand-operated multiple-unit control system, line current operation, four 1200-volt motors.

The current for the auxiliary control circuits for a 1200-volt system may be taken from a 1200-volt control resistance in the same manner as for a 600-volt system with low voltage taps for the valve magnet or contactor circuits, or a continuous running dynamotor may be used operating on 1200 volts and supplying current at 600 volts for the auxiliary control and car lighting circuits. This dynamotor is also arranged to drive the air compressor, being equipped with an air-controller clutch, which automatically connects and disconnects the compressor when the main reservoir air pressure falls below or rises above certain predetermined values.

Fig. 32 shows the main and control circuit wiring for a quadruple equipment of 1200-volt 40-h.p. motors with straight 1200-volt type HL control.

Westinghouse PK Control

Main Controller. The Westinghouse type PK controller consists of a mechanically operated drum type controller whose operation is controlled by a master controller, line switch and current limiting switch. The drum type controller originally intended for hand operation may be placed beneath the car and used as the main controller in the PK system. The mechanism which operates the main controller drum (see Fig. 33) is mounted on a base which takes the place of the usual controller case top. This consists of a pair of cylinders whose common piston rod carries a rack which meshes with a pinion on the shaft of the main controller drum. Valves admitting compressed air to and from these cylinders are controlled by magnets. When the "on" valve magnet is energized, compressed air is admitted to the "on" cylinder, and when the "off" valve magnet is energized, air is released from the "off" cylinder. When both of these magnets are energized, the main drum is moved in a clockwise direction and when both of them are de-energized, this drum is moved in a counter-clockwise direction. If, during clockwise motion of the drum, the "off" valve magnet only be de-energized, the motion of the drum will stop. In order that the main controller drum will stop at the notches, an auxiliary control or interlock drum having points corresponding to those of the main drum is keyed to the shaft of the main drum. This

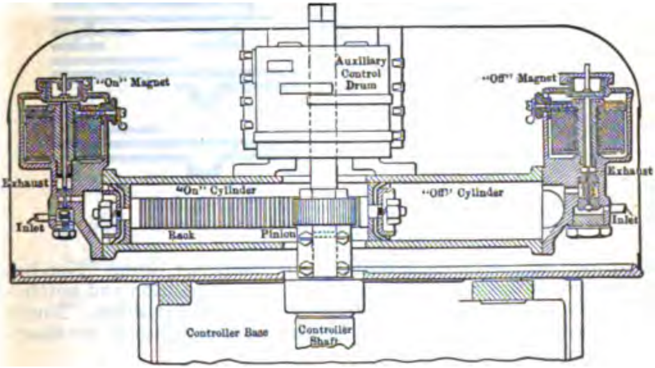


Fig. 33.—Westinghouse PK control, operating mechanism.

interlock drum breaks the control circuit of the "off" valve magnet. Each notch is controlled by a separate control wire energized from the master controller.

Reverser. The common piston rod of two opposed cylinders is linked to a lever on the reverser drum shaft. Motion of the reverser drum is secured by admitting compressed air to one or the other of these cylinders.

Main Control Circuits. Fig. 34 shows the main control circuits for a two-motor field-control equipment. The making and breaking of the main circuit is done by an electropneumatic line switch. An overload trip protects against overload and short circuit. The "off" position of the main controller corresponds to the first notch on the master controller. There are four series and four parallel notches on the main controller drum. Notches 2 and 3 cut out resistance steps in the series position and notches 6 and 7 cut out resistance steps in the parallel position. Notch 4 (series) and notch 8 (parallel) change from full-field to short-field connections.

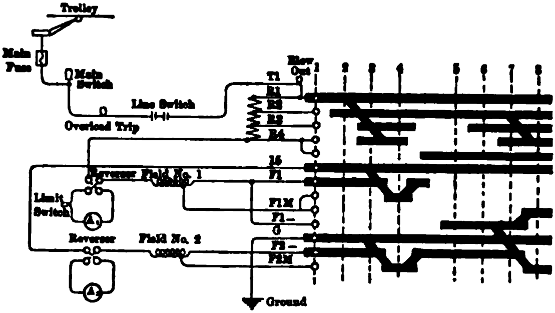


FIG. 34.—Scheme of circuits, Westinghouse PK control.

Master Controller. The master controller has two handles, the main handle and the reverser handle. If the motorman releases the main handle when it is not in the "off" position, power will be automatically cut off and the brakes applied. The emergency brake application may be prevented in the "off" position by moving the reverse handle to neutral. A sliding contact (Fig. 35) clamped around the shaft of the main drum of the master controller is allowed by a stop to turn through an angular distance corresponding to one notch of the main drum, but during the rest of the movement it is held stationary. By this arrangement the control circuit for the line switch is established as the master controller is moved toward the "on" position, but a backward movement of the master controller handle opens the circuit and drops out the line switch. Thus there is no arcing on the main controller drum in returning toward the "off" position.

Master Control Circuits. (Fig. 35.) On the first notch of the master controller, wire 1 is energized from 6, which is the positive side of the control circuit. Wires *F* and *R* are energized from the wire 0, which is the negative side of the control circuit. Wire 1 is interlocked through the main controller drum in the first position, to wire 13, to the line switch valve magnets, to the return circuit through wire 10, which is interlocked through the reverse drum to wire *F* or *R*, and then through the reverse drums and sliding contacts on the master controller to the negative side of the control circuit. As soon as the line switch closes, wire 13 is connected to wire 1, which establishes a holding circuit. Current through wire 1 also energizes the "on" valve magnet which is connected directly to the first position until the master controller is thrown to the "off" position. On the second notch of the master controller, wire 2 is energized, and the current goes directly to the auxiliary interlocking drum on the main controller, which energizes the "off" valve magnet through wire 14 and the limit switch to the "off" valve magnet coil, and returning to the negative side of the line through wire 10. This releases the air from the "off" cylinder, and the "on" valve magnet being already energized, the main controller drum moves toward the second position. Just before it reaches the second position, the current in wire 2 is interrupted on the auxiliary control drum thus de-energizing the "off" valve magnet which instantly establishes equal pressure in both cylinders, stopping the main drum on the second position. The control wires 3 and 4 operate in a similar manner, and control the resistance and field notches in series as well as in multiple. The *P* wire when energized operates the main controller drum from the series to the multiple position.

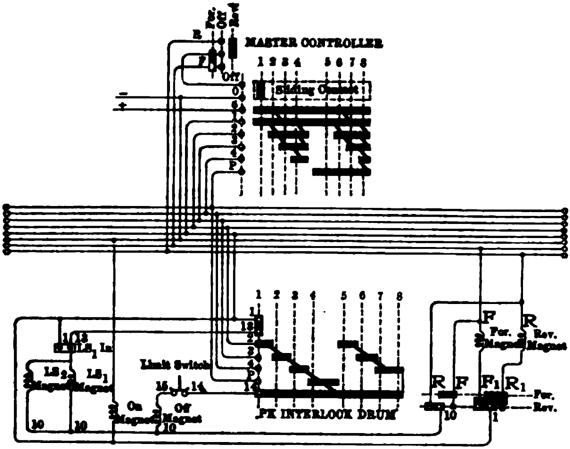


Fig. 35.—Circuit diagram, Westinghouse PK master controller.

Automatic Acceleration. The master controller handle may be thrown directly to the full parallel position and a rate of accelera tion will be maintained as predetermined by the setting of the current limit relay.

Source of Power for Control Circuits. Power for operating the control circuits may be obtained from a storage battery or from the trolley through a control resistance.

Field Control

Method. Field control is practicable with commutating-pole motors. The field winding of a motor with which field control is to be used is (ordinarily) divided into two parts. When these two parts are connected together in series, a strong field and therefore low speed is obtained. For a higher speed a weaker field is secured by cutting one part of the field winding entirely out of the circuit. By this arrangement there are two series running positions and two parallel running positions, thus making four running positions where, without field control, there would be but two. The ordinary drum type of controller may be arranged to make the necessary connections for field control or multiple-unit control may be adopted by the use of extra switches in the motor controller or by the addition of a field change-over switch similar to the reverser switch. (See Fig. 34.)

Range of Speed Covered by Field Control. An article by Mr. N. W. Storer, Electric Railway Journal, 1913, states that the range of speed that may be covered by car field-control equipments is usually from 15 to 25 per cent., which may be secured by cutting out 20 to 40 per cent. of the field turns. This article also states that it will generally be found most economical to have the speed of the motor with the short field 20 to 25 per cent. higher than with the full field. The extent to which field control may be carried depends largely on the average voltage between commutator bars. With a comparatively high average voltage between adjacent commutator bars the weakening of the field may not be carried so far without materially affecting commutation as may be with a low average voltage between bars or, in general, of two motors wound for the same voltage, the one having the greater number of commutator bars will commutate satisfactorily over the greater range with field control. On the Pennsylvania locomotives the field turns are reduced 50 per cent. in three steps on the controller and there are eight running notches.

Advantages of Field Control. Advantages gained through the use of field control may be outlined as follows: A saving in energy is brought about, motors equipped with field control will operate satisfactorily in both city and interurban service, a smaller motor may be used for a given service, more running speeds are made possible, and where service is infrequent and where field control is used, maximum power requirements are reduced.

Energy Saving. The full field is used during the straight line acceleration period and the field control is used instead of the last resistance step, thus the control resistance is cut out at a comparatively low speed and a saving in rheostatic losses is thereby brought about. By the field control the train may be brought to the same maximum speed as would be attained without field control, consequently, braking losses need not be increased. The following data are from a table of a series of tests made on cars of the Metropolitan Street Railway Co., New York:

Test No.	Weight of loaded car, tons	Gear ratio	Stops per mile	Slow-downs per mile	Average length of stop, seconds	Schedule speed, miles per hour	Watt-hours per ton mile
2	19.729	5.12	6.778	3.08	7.765	7.261	141.63
4	19.714	5.12	6.881	3.56	7.335	7.409	124.41

The number of stops per mile and the other service conditions were practically the same in both tests, but in test No. 4 full use was made of field control in both series and parallel; 40-h.p. motors were used in both cases. A comparison of the watt-hours per ton mile shows a saving in energy of 12.2 per cent. by field-control. A paper by Mr. J. L. Davis before the Wisconsin Electrical Association, 1912, states that exhaustive tests on a two-motor field control equipment in congested city service showed a saving of 12.5 per cent. in energy consumption, or a saving of $75 to $100 per car per year over a similar equipment without field control. An article by Mr. N. W. Storer, Electric Railway Journal, 1913, states a belief that in most classes of service the use of properly designed field-control equipment will effect a saving of not less than 10 per cent. in the energy consumed in operating cars. An article by Mr. J. L. Davis, Electric Journal, 1910, states that the loss during acceleration of the Pennsylvania locomotives is only 55 per cent. of what it would be without field control.

City and Interurban Service. With field control a motor may be given such a high gear ratio that when operating on full field a sufficiently high rate of acceleration and economical operation is secured in city service, while the same equipment run on short field will give a satisfactory speed in interurban service.

Adaptation of Field Control to Existing Motors. The following points on the adaptation of field control to existing equipments are from an article by Mr. N. W. Storer, Electric Railway Journal, 1913. In most cases it is impossible to adapt field control to city service and effect any considerable economy. This is especially the case where the motors are already provided with the maximum gear reduction. In such a case the possibility for saving is very limited since the standard motors are usually worked at a fairly high induction at normal accelerating loads and the induction can be increased very little by the addition of extra turns on the field coil. There will, therefore, be very little decrease in the accelerating current and a correspondingly small decrease in speed. Consequently, the saving in rheostatic losses would be very small and not enough to pay for a change in the equipments. The use of fewer turns on the field for obtaining higher speed would be of no advantage whatever where the equipment is already geared for speed as high as is required. To get the advantage from field control in slow city service, motors must be wound for slower armature speed than is ordinarily used for standard motors. This will in most cases require new armature windings. Where interpole motors are now used with large pinions the advantages of field control can be secured in most cases by an increase of the gear reduction, a change in the field winding and by making the necessary changes in the control equipment. These changes in most cases cost so much as to be prohibitive unless made at a time when gears are to be changed and motors overhauled. It should be kept in mind, however, when new equipments are bought and when all the advantages may be secured at a minimum cost.

Field control with non-commutating-pole motors cannot be recommended, as it will result in most cases in trouble with commutation.

Any well-designed commutating-pole railway motor may be adapted for field control by a proper arrangement of its field windings. To get the full benefits, however, the gears must be properly selected. For interurban work the benefits of field control may be secured by the use of standard high-speed armatures with a larger gear reduction than usual. In most cases, also, sufficient space is available to permit the extra field winding to be used. Special armatures for use with field control are necessary only for cases where the slowest speeds and the maximum gear ratio are required. It will usually be found that where a motor of a given size is used in city service with the maximum gear reduction and the usual series-parallel control a slower speed armature may be used with the same motor frame and will make the same schedule with a lower energy consumption when field control is employed.

The motor will have a lower horse-power rating, but the current used will be correspondingly less, and, consequently, the motor will have no more loss in it than with the motor of higher speed with a larger rating. In other words, the use of field control permits the use of a motor of a smaller rating for a given service. Where the maximum gear ratio is used in both cases, the same size of frame must be used. However, where the gear reduction can be increased for the field-control motor it will frequently be found that a smaller size of motor can be used at a lower first cost and with less weight to be carried around. A double saving will thus be effected.

Single-phase Series Motor Control

The single-phase series motor is controlled by adjusting the electromotive force applied to the motor. The three methods of making this adjustment are: (1) By resistance in series as in ordinary direct-current series motor control. (2) By compensator. (3) By induction regulator. The latter two are more efficient than the first because by their use the heavy resistance losses which would occur in the resistors by the former method are saved. The second is a widely used method and is generally known as the tap potential control (see Fig. 36) and the function of the control,

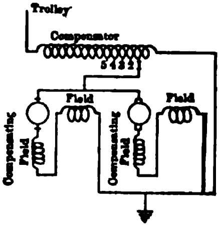


FIG. 36.—Tap control for A.C. motors.

whether it be hand-operated K type or multiple unit, is to successively connect the motor terminals to transformer taps of increasing potential while starting.

Hand-operated Control. The hand-operated control is identical with the type K controller used with direct-current motors, except that advantage is taken of the fact that alternating-current arcs of considerable size can be broken in the air without the aid of the magnetic blowout. Where the cars are to be operated from both alternating-current and direct-current trolley with the same equipment, the hand-operated control is provided with magnetic blowout for direct-current running, using the same controller without the magnetic blowout for alternating-current running, unless the motor equipment be of large capacity.

Compensator. The compensator or single-coil step-down transformer is wound for 3000, 6000 or 10,000 volts trolley potential. Upon its grounded side there are several taps brought out to facilitate starting, and it is customary to connect two motors in series when operating alternating current in order to approximate 500 volts input and thus reduce the size of the contact surface required in contactors. The compensator is encased in a corrugated iron case containing oil and is self-cooled. Owing to the fact that the alternating-current motor characteristic is more drooping than that of the direct-current series motor, fewer starting points are required for alternating-current control. The General Electric Company uses five steps when the speed does not exceed 40 to 45 miles per hour maximum. As each point on the controller with potential tap control constitutes a running point at full efficiency, it is not necessary to use series-parallel connection of motors as is done with direct-current motors. If while passing from one compensator tap to the next without opening the circuit the gap were bridged by a connection of very low impedance, a heavy current would flow in the portion of the compensator winding thus short-circuited. To hold this current at a low value an inductance or a non-inductive resistance (termed, in this application, preventive inductance and preventive resistance, respectively) is placed in the circuit. Fig. 37 shows the application of the inductance (preventive coil).

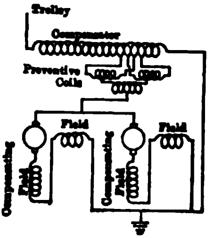


FIG. 37.—Tap control for A.C. motors, with preventive coils.

Reversing. Reversal is effected by reversing the series field windings as in direct-current control.

Power Operated Control. The master controller is similar to the direct-current master controller. Its office is to energize the train wires in proper sequence. Current of proper potential is obtained from transformer taps.

The contactor is similar to the direct-current contactor, except that it is designed for operation on both alternating current and direct current, and therefore has its magnetic parts laminated. These contactors connect the motors with transformer taps or with starting resistance grids, depending upon the character of the supply current.

Combined Alternating- and Direct-Current Control. (Fig. 38.) Owing to the fact that alternating-current series motors are wound for potentials of approximately 225 volts per motor, and that such motors in order to meet the exactions of commercial operation must also be adapted to run with 600 volts direct current, some additional features in control are required to perform this double service of alternating-current and direct-current control. When both alternating-current and direct-current running are to be accomplished with the same control it is necessary to effect the following changes when changing from alternating current to direct current and *vice versa*.

Step	Sequence of Switches D.C. Operation.																			
	LS_1	LS_2	M_1	M_2	S_1	S_2	F	J	JR	R_1	R_2	R_3	R_4	R_5	RR_1	RR_2	RR_3	RR_4	RR_5	G
Off																				
1	O		O						O											
2	O		O		O				O											
3	O		O		O	O			O											
4	O		O		O	O			O	O										
5	O		O		O	O			O	O					O					
6	O		O		O	O			O	O	O				O					
7	O		O		O	O			O	O	O				O	O				
8	O		O		O	O			O		O	O			O	O				
9	O		O		O	O			O		O	O				O	O			
10	O		O		O	O			O			O	O			O	O			
11	O		O		O	O			O			O	O				O	O		
12	O		O		O	O			O				O	O			O	O		
13	O		O		O	O		O					O					O		
14	O		O		O	O		O										O		
15	O		O		O	O		O												
16	O	O	O	O	O	O														O
17	O	O	O	O	O	O														O
18	O	O	O	O	O	O				O					O					O
19	O	O	O	O	O	O				O	O				O	O				O
20	O	O	O	O	O	O				O	O	O			O	O	O			O
21	O	O	O	O	O	O				O	O	O	O		O	O	O	O		O
22	O	O	O	O	O	O							O	O				O	O	O

Step	Sequence of Switches A.C. Operation.																			
	CB	M_1	F	J	S_1	S_2	RR	O	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Off	O																			
1	O	O	O		O	O														
2	O	O	O		O	O														
3	O	O	O		O	O														
4	O	O	O		O	O			O											
5	O	O	O		O	O			O	O										
6	O	O	O		O	O			O	O	O									
7	O	O	O		O	O			O	O	O	O								
8	O	O	O		O	O				O	O	O	O							
9	O	O	O		O	O					O	O	O	O						
10	O	O	O		O	O						O	O	O	O					
11	O	O	O		O	O							O	O	O	O				
12	O	O	O		O	O								O	O	O	O			
13	O	O	O		O	O									O	O	O	O		
14	O	O	O		O	O										O	O	O	O	
15	O	O	O		O	O											O	O	O	O

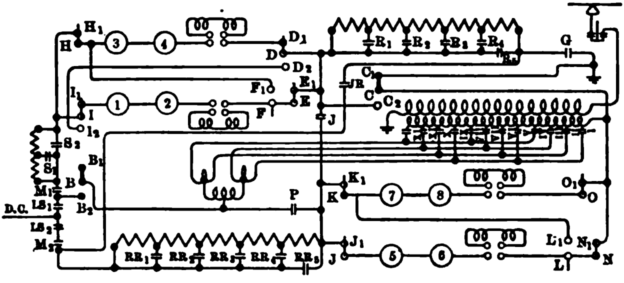


FIG. 38.—Circuits and sequence of switches, New Haven twin-motor locomotive (eight motors), alternating- and direct-current operation.

Change main line fuses or circuit-breakers.
Change lightning arresters.
Change motor field-winding connections.
Change transformer taps to resistance taps.
Incidental changes in car-wiring connections.

To effect these changes with a minimum amount of delay, all the necessary contacts are concentrated upon one cylinder in an auxiliary controller, so that a single movement will effect all changes simultaneously.

Retaining Coil. In changing from alternating-current to direct-current trolley and *vice versa*, it is necessary to guard against the possibility of wrong connections upon the car for the current received, that is, to prevent disaster should connections be made for 600-volt direct-current operation and accidental contact be made with high voltage alternating trolley. To guard against this, the main switch of the direct-current, alternating-current car equipment is provided with a retaining coil so designed that it will open when the motor current is interrupted. Where alternating-current and direct-current trolley sections adjoin, a dead section is left between the two for a length not exceeding a car length, so that a car may pass from one section to the other at full speed, in which case the main car switch opens on the dead section through lack of power to operate the retaining coil, and will reset automatically for alternating-current or direct-current operation as the case may be, after leaving the dead section.

Connections to Air Compressor. The air compressor is geared to a single-phase motor wound for operation with 500 volts alternating current or direct current, and it is customary to wind the motor fields in two parts connected in multiple for alternating-current and in series for direct-current running, these changes being effected through the medium of the commutating switch.

Induction Regulator. Due to great weight, low power factor and lack of simplicity as compared with the tap potential method, the induction regulator method is at a disadvantage in controlling alternating-current traction motors. The induction regulator is a special type of transformer, so arranged that one winding may be adjusted relative to the other, mechanically. It is commonly built like an induction motor having a coil-wound rotor and a very short air gap which is permitted since there is little motion and negligible bearing wear. The rotor winding is generally the primary. The primary is connected across suitable taps of the transformer, and the secondary, in series with the motor, is also connected across suitable transformer taps (see Fig. 39). The electromotive force induced in the secondary of the regulator due to the current in the primary may be adjusted by turning the coils relative to each other, and it may be made to buck or boost the electromotive force applied to the motor, from the transformer directly, by any amount within the range of the regulator. Thus the net electromotive force applied at the motor terminals is adjusted. On the single-phase locomotive of the Dessau-Bitterfeld line of the Prussian-Hessian State Railway gradual change of voltage is obtained by means of an

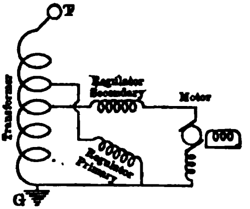


FIG. 39.—Induction regulator control.

induction regulator which covers a range of one step on the main transformer. The first position of this regulator lowers the transformer voltage by one-half step. On turning the induction regulator the voltage reduction gradually drops to zero; that is to say, the resultant voltage is the mean value between the two successive transformer taps. As the turning is continued the regulator delivers a rising additional voltage which gradually reaches the value of one-half step and thus equals the next higher step on the transformer. In this way the voltage changes from step to step are made without shock. The switching from one step of a transformer to the next is automatically obtained by means of a switch which is coupled to the induction regulator. The small single-phase motor which is used for turning the induction regulator is cut out automatically as soon as the voltage of the traction motor has reached its highest or lowest value as the case may be. This small motor and the various contactors in the motor circuit are operated by low voltage current taken from the main transformer.

Three-phase Induction Motor Control

The three general methods of controlling the speed of a three-phase induction motor are (1) rheostatic; (2) changing the number of primary poles; (3) cascade operation. The first method is used in connection with the other two, at least during the straight line acceleration period.

Reversing. A three-phase induction motor may be reversed by interchanging two of the three leads which supply the energy to the primary windings of the motor.

Rheostatic Control. In this method the proper tractive effort during the straight line acceleration period is secured by adding resistance to the secondary winding of the induction motor. For railway work the windings of the secondary are brought out to slip rings and the added resistance in the form of grids or liquid is external to the motor circuit. The grid resistance is cut out in steps as the motor speeds up and is short-circuited at the last step. Where liquid resistance is used, its value is reduced steadily, thus securing a steady acceleration. The electrodes which dip into the liquid are held stationary and in the process of reducing the resistance, the level of the liquid is raised by compressed air, the influx of which is regulated by an air valve controlled by a magnet in the motor circuit. Finally the resistance is automatically short-circuited by a switch governed by a float. To return the resistance to its starting value the liquid is depressed by air pressure. Ordinarily the secondary winding of the motor is three-phase; the external control resistance is star connected and is customarily kept balanced throughout adjustment. With a view, however, to simplifying apparatus this external resistance is sometimes unbalanced. Such unbalancing is used in the control of the four motors which drive each of the 115-ton locomotives operating through the Cascade Mountain tunnel on the Great Northern Railway. Each motor is three-phase, 25-cycle, 500-volt, 475-h.p. with a gear ratio 4.26 driving 60-in. wheels. The following, relative to this particular installation, is from a paper by Dr. Cary T. Hutchinson, A.I.E.E., 1909: "The control system of each motor is separate; the circuits branch from the transformer and are independent through the resistance. There are 14 contactors in each motor circuit, 56 in all. . . . . Iron grid resistances are provided for each motor; there are thirteen steps in the control, but in order to reduce the number of contactors to the lowest possible point an unsymmetrical system is used. A change is made in the resistance of one phase only, in passing from step to step. This arrangement in effect treats the three-phase circuit as a single-phase circuit; on each step of the control the torque is the average of the three values of the torque of the separate circuits. The principal advantage of this is that 56 contactors do the work that would otherwise require 128, thus effecting a great gain in the simplicity of the control apparatus."

Because of the resistance loss in the added external resistance in the secondary circuit the rheostatic method of induction motor control is inefficient. The net mechanical energy output of the motor is equal to the energy input to the secondary of the motor, diminished by this secondary copper loss at that instant.

Changing the Number of Primary Poles. (See page 268 for a method of determining synchronous speed.) A motor may be arranged so that the number of its primary poles may be changed, thus giving more than one efficient running speed. The number of poles may be changed by re-grouping the coils of the motor primary winding or by using an independent primary winding for each number of poles desired. The re-grouping method is generally preferable because in its application all the motor primary windings are used.

Cascade Operation (Also referred to as **Tandem Control** or **Concatenation**). A great many variations are possible in concatenation. In railway work two motors are used. Two motors may be operated in direct concatenation to give half speed and then operated in parallel to give full speed and the advantages thus gained will be analogous to those gained in series-parallel control of direct-current motors. Concerning concatenation the following useful comparison is drawn by Mr. B. G. Lamme, Electric Journal, 1909: "This corresponds to two or more direct-current shunt motors with their armatures connected in series. If both armatures are wound for equal speeds, then the tandem or series connections give half speed, as with the alternating-current motor. If one direct-current armature is wound for a higher speed than the other, which corresponds to two alternating-current motors with different numbers of poles, then four speeds may be obtained corresponding to the windings connected cumulatively, differentially and to each motor used separately. This corresponds to the four speeds of the alternating-current combination where two motors have different numbers of poles and are connected in tandem to give speeds corresponding to the sum or difference of the number of poles or are operated separately."

For concatenation of two motors for railway service, the rotors of the motors are mechanically connected, the primary of the first motor is connected to the supply, the secondary of the first motor is connected to the primary of the second motor and secondary of the second motor is connected to an external resistance at start. As the concatenated set speeds up the resistance in the secondary of the second motor is reduced and finally this secondary is short-circuited just as in the rheostatic method of control outlined above. If the motors have the same number of poles and are operated in direct concatenation they may, after having reached their normal maximum speed (synchronous speed of the set minus the slip), be separated and each, having resistance inserted in its secondary, may have its primary connected to the supply. From this point the resistance in the secondary circuits may be reduced as in the ordinary rheostatic method of control outlined above, finally leaving the secondaries short-circuited and the motors operating in full parallel on the line. Two running speeds using both motors are thus secured.

Cascade-single Control. This method is similar in operation to the method just outlined except that the second motor (termed the auxiliary in this use) is cut out entirely beyond the period of concatenation.

Cascade-parallel-single Control. This method is between the two previous methods (parallel and cascade-single). The motors have a different number of poles or the same number of poles with different gear ratios. This method is similar in operation to the parallel method except that during acceleration beyond concatenation the motor with the greater number of poles reaches synchronism and is cut out before the motor with the fewer poles reaches its maximum running speed. If the motor having the fewer poles be cut out when the one having the greater number of poles approaches synchronism the train will operate at a running speed between that for the set in concatenation and that for the motor having the fewer poles when running free with its secondary short-circuited.

Combination of Concatenation and Changing the Number of Poles. If several running speeds are desired this may be accomplished by changing the number of poles in one or both motors in the manner previously outlined and then proceeding with one of the methods of concatenation.

Synchronous Speed of Two Concatenated Motors; *Motors in Direct Concatenation.* Two concatenated motors are said to be in direct concatenation when they are so connected that they tend to start in the same direction. The synchronous speed of a set so connected is given by:

$$S = \frac{f \times 120}{p_1 + p_2}$$

in which S = synchronous speed, revolutions per minute

f = frequency of supply, cycles per second

p_1 and p_2 = the number of poles per motor, respectively.

Motors in Differential Concatenation. Two concatenated motors are said to be in differential concatenation when they are so connected that they tend to start in opposite directions. The synchronous speed of a set so connected is given by:

$$S = \frac{f \times 120}{p_1 - p_2}$$

in which the significance of the symbols is the same as in the previous paragraph.

OVERHAULING AND INSPECTION OF CONTROL APPARATUS

(A.E.R.E.A. Miscellaneous Methods and Practices)

Type K Controller. The equipment should be given a thorough overhauling for every 60,000 miles of service as follows: The controller should be taken apart, thoroughly cleaned, defective parts replaced, wood scraped and shellaced and other parts of the controller painted with insulating paint. The controller should then be given a break-down test of not less than 1500 volts alternating current for 5 seconds. With controllers in good condition, periodical inspections on a basis of from 300 to 500 miles service—depending upon the conditions of operation—will be sufficient and the most economical. Careful attention should be given to the fit of the controller and reverse handles on spindles.

Inspection of GE Type M Multiple-unit Control Apparatus. *Master Controller.* Examine the master control fingers, trying tension of fingers and polishing cylinder and fingers to secure good contact. Scrape carbon dust from arc-deflector division plates. Wipe dust off inside of cover. Examine controller throughout for loose connections and see that each finger is adjusted to make good contact. Lubricate fingers and cylinder with small amount of vaseline. Press down button on controller handle to see that the auxiliary fingers make proper contact, and polish up the same when necessary. Oil sparingly the shaft bearings of cylinder and reverser switch. Wipe off excess lubricant, especially around the blow-out coil. When finished, try on each point to see if contactors pick up properly, also throw reverser two or three times. Blow out controller with air hose.

Contactors. Scrape arc chutes clean of carbon and copper dust and examine the tips, filing up any that are blistered to make sure of good contact on all. Press up under contactor fingers to see if bottom tip wipes or travels on top tip at least one-eighth of an inch. If tip is worn thin or so as to give less than one-eighth of an inch wipe renew the tip. Try all screws which secure the tips to the contactor arms, making sure that all screws are absolutely tight. Examine for loose connections and try all screws and bolts to make sure that they are all tight. A long screw-driver arranged to turn it with a wrench at bottom is desirable for this purpose. Inspect interlock fingers and polish up tips to insure good contact. If interlocks are bent out of shape, bend back into such shape as to make proper contact. Examine all shunts to see that none are partly broken or any in such condition that they will not have full carrying capacity, thus preventing danger of burning the hinge pins. See that contactors will lift sharply on each point and drop freely when controller is shut off. Before shutting the contactor box take air hose and blow out the contactors and box thoroughly clean.

Reversers. Try all screws to finger and connections to see that they are tight. Examine all fingers, filing fingers and contacts insure a good contact. Feel tension on each finger, and renew if finger has been heated and softened. Make sure that each finger will make square and firm contact with segments. Wipe off all segment blocks, and if there is any indication of shorting across between segments remove segment block and replace with one that has been cleaned up and varnished. Throw rocker by hand a few times to see that the fingers will not catch. Throw reverser electrically a few times to see that it throws with strength and promptness without undue arcing and without rebound. When reverse finger is not making good contact it can sometimes be detected by tapping the finger with a screw-driver handle or by placing a thin strip of paper between the finger and the contact and noting the way the paper pulls.

Overhauling Type M Multiple-unit Control Apparatus

Overhauling should be on a 60,000-mile basis as follows:

All coils removed from the contactor, reverser and circuit-breaker; boxes thoroughly cleaned and painted with an insulating paint. Interior of boxes cleaned and painted; contact strips between coil frames inspected for loose contacts; all working parts thoroughly inspected and worn parts replaced when necessary; wires inside of contact box thoroughly painted and when reassembled given an insulation test of 1500 volts alternating current. It would then seem that periodical inspections on a basis of from 600 to 900 miles of service would be satisfactory.

The following points are suggested as requiring attention at such times. Examine for broken shunt straps and broken hinge pins. See that interlocks are properly adjusted and that small arcs do not form between the fingers and disks, thereby burning finger and disk, which would eventually cause a defective contact at this point and a dead car. Clean the disk and finger with fine emery cloth. Keep the arc chutes and plates clear of all copper caused by contactors breaking current. See that all connections are tight. See that springs are not broken and are in good order insuring good contact when closed. See that plungers do not bind and that contactors break free when the current is thrown off. Contact plates should not be worn so low that screws holding them are burned. Blow out contactor box with compressed air. Note condition of wiring in the box. Clean the master control cylinder and use a small amount of vaseline on the fingers. See that the handle is of proper fit and works perfectly free. The adjustment of controller should be looked after very carefully, as there are no adjustment screws on the contact fingers. Note condition of throttle. Clean throttle disks and fingers and see that adjustment nuts are not loose. Do not clean throttle plunger unless it shows signs of sluggishness. Great care must be taken when cleaning plunger. Clean reverser and note adjustment and condition of plates and fingers and that the reverse throws in properly. Use no oil or grease on contactor or reverser finger or plates. A great deal depends on the close adjustment of interlocks. All bearings on contactors and interlocks must be made loose. When a contactor box becomes coated inside with a yellow coating caused by the burning of copper, short circuits are very likely to occur if this is not cleaned off.

Overhauling Electropneumatic Control Apparatus. Overhauling should be on a 60,000-mile basis as follows:

Clean the drum and adjust fingers of master switch; inspect cab switch terminals and see that they are held rigidly and no strands of wire are broken. Repair, clean and carefully adjust line relay, limit switch and battery relay. Limit switch should be adjusted with ammeter. Take apart, clean, scrape and shellac drums of motor cut-out switch and reverser; replace any parts that will not make the mileage and adjust the finger tension. Strip switch groups of all magnets, switch arms and moving parts, replace worn parts when necessary. Replace worn or broken arc shields; adjust all magnet valves to operate at proper voltage; replace defective shunts; adjust and clean all interlocks and interlock fingers; examine all insulation and make as good as new; examine piston leathers and see that they are flexible and replace those badly worn. Storage batteries should be cleaned of sediment and acid strength adjusted. Grid diverters should be cleaned, the insulation renewed where necessary, and all connections tightened. Control jumpers should be tested by passing 7 amperes of current through them for 3 minutes, at the same time giving jumper the same motion that it has when in service. Clean and adjust circuit-breaker; thoroughly blow out all piping and air chambers connected with the control.

On short period inspection the following is the practice on a road having inspection periods based on a 600-mile service.

Master Switch. Clean and lubricate every tenth inspection.

Cab Switches. Inspect terminals every inspection day.

Close jaws of cab switch to fit tight each inspection day.

Line Relay and Limit Switches. Clean with crocus cloth each tenth inspection. Inspect connections each inspection day.

Motor Cut-off Switch and Reverser. Inspect finger tension and oil drum contactor each second inspection and feel the terminals to see if the wires are O.K.

Inspect interlocks each twelfth inspection.

Oil reverser switch toggle each tenth inspection.

Circuit-breaker and Switch Group. Clean armature and valves each tenth inspection. Inspect contacts each inspection day. Clean arc chutes each inspection day. Blow out with compressed air all switches and grid diverters each third inspection. Inspect all grid diverter connections and oil all pistons each inspection day, see that all terminals are tight and inspect wires. Wipe off insulators. Inspect shunts and battery connections each inspection day. Add distilled water to take care of evaporation when necessary. Test specific gravity each thirtieth inspection day. Test battery relay and inspect terminals of battery switches each inspection day.

Cost of Maintenance and Inspection of Multiple-unit Control Apparatus. The following is from the 1912 report of the Joint Committee on Train Operation, A.E.R.E.A.: "In determining the figures for the cost of maintenance for control and miscellaneous electric apparatus, the Committee encountered the greatest difficulty, particularly in the maintenance where multiple-unit control is involved, and after looking over the figures obtained from companies using multiple unit, the Committee came to the conclusion that there was no actual comparable data on which they could base the maintenance figures for this type of control. After a large amount of time was consumed in the discussion of this subject, the Committee decided, in conjunction with representatives of the manufacturers, that an increase of 50 per cent. be made for the maintenance of multiple-unit control over that of K control, these figures applying to congested city service. The manufacturers do not admit that maintenance of multiple-unit control will be 50 per cent. over that of K control, but this is a comparatively small percentage of the total."

Cost of Maintenance per 1000 Car Miles of Multiple-unit Control Apparatus. The following are from the Question Box, Aera, 1912:

Wm. G. Gove, Supt. of Equipment, Brooklyn Rapid Transit System, Brooklyn, N.Y.

Total cost of maintaining multiple-unit control apparatus, fiscal year 1911–12	$54,068.33
Total car mileage, fiscal year 1911–12	34,078,709.00
Cost per car mile	$0.00158

Of the 928 cars included in the above, 660 of these are motor cars and 268 are trailer cars. The above costs include the maintenance of the actual control equipments, as well as car wiring, resistance, etc., but do not include the train line or bus line jumpers, the maintenance of these being charged to Operation. I might add that the cars equipped with the multiple-unit control system are operated on our elevated lines.

E. F. Gould, Asst. to Gen. Mgr., Aurora, Elgin and Chicago Electric Railroad Co., Wheaton, Ill. Cost of maintenance per 1000 car miles of multiple-unit control apparatus:

Fiscal year 1910–11	$0.857
Fiscal year 1911–12	0.841

Control consists of one G E type M, electrically operated reverser and 13 electrically operated contactors for each pair of GE-66 motors. Some of the cars have two-motor equipments and some four-motor equipments, but the following table is on the basis of two motors with one set of contactors and reverser forming one equipment.

AGE OF EQUIPMENT

20 equipments	10 years
28 equipments	9 years
16 equipments	5 years
14 equipments	3 years
3 equipments	1 year.

Total, eighty equipments in service on forty-seven motor cars. In addition there are eight trail cars each equipped with two C-21 controllers, bus line and control line coupler with cables. The costs given include all maintenance costs with C-21 master controllers, of which there are two on every car, also on the bus and train line sockets, and jumpers with fuses and connection boxes, but no wiring.

L. M. Clark, Master Mechanic, Terre Haute, Indianapolis & Eastern Traction Co., Indianapolis, Ind. Our maintenance cost per 1000 car miles for Westinghouse Unit Switch Control of the AB or automatic-battery type, based on the record of the 6 months ending June 30, 1912, is $1.243. This figure includes all labor and material involved in the maintenance of the control apparatus, including the grid resistors and control cables, comprising fifteen quadruple equipments of 90-h.p. motors operating in high-speed interurban service for a total period of 6 years. We consider this cost somewhat high, which is attributable to the labor costs incidental to the comparatively small number of equipments, as our present facilities are capable of taking care of approximately twice the number.

Wear of Multiple-unit Switch Fingers. In an article by Mr. Clement F. Street, Electrical Journal, 1906, it is stated that multiple-unit switch fingers have been subjected to most severe tests and several of them have broken the current to which they are subjected in service one hundred thousand times without being worn out.

SECTION VI

CURRENT-COLLECTING DEVICES

Composition of Trolley Wheels. (A.E.R.E.A., Miscellaneous Methods and Practices.) There seems to be no good reason for a different quality of bronze for wheels in city service from those in interurban service. Among the formulas submitted are the following:

	Per cent.		Per cent.		Per cent.		Per cent.
Copper	90.0	copper	91.0	copper	91.38	copper	96.0
Tin	8.0	tin	7.0	tin	6.5	tin	3.0
Zinc	2.0	zinc	1.5	zinc	2.0	phosphor tin	1.0
		flux	0.5	lead	0.12		

Trolley Wheel Bushings and Lubrication. For both city and interurban service the bronze and graphite bushing is in almost universal use, the graphite lubricant being supplemented by a few drops of oil from a squirt can at each inspection.

Types of Trolley Wheels. *City Service.* The wheel principally used on the larger city systems runs to fairly uniform practice, being 4½ in. outside diameter, with a ¾-in. V groove, 1½ by ½ in. bronze and graphite bushing, and weighing from 2 to 4 lb. Some wheels as small as 4 in. outside diameter are in use, but these show materially shorter life than wheels 4½ in. or larger. For city service a wheel of not less than 4½ in. outside diameter is recommended as the best practice. The use of a 1½ by ½ in. bushing is the practice of a large majority of city roads. There does not seem to be much tendency toward a bushing longer than 1½ in., probably because such a bushing would require a wider harp, which would be more likely to damage the overhead line particularly at special work if the trolley should jump. It is recommended that where the trolley wheel axle is ½-in. diameter by 1½-in. length in hub proves to be too small for the service required of it, its diameter be increased rather than its length.

Interurban Service. Data on interurban trolley wheels show a rather wider diversity of practice than for city wheels the outside diameter varying from 4¼ to 8½ in. In general, the larger the diameter of the wheel used, the better the mileage performance shown. Excessive weight of wheel is regarded as an element of danger, and it is recommended that no trolley wheel weigh more than 5 lb. Also, that the weight of harps equipped with trolley axles, contact springs, washers, etc., complete, does not exceed 3 lb. each, and further the outside diameter of trolley wheel be not less than 6 in. Trolley wheels for interurban service having axles ½ by 1½ in. are not regarded as the best practice, and in view of performance of wheels with axles ¾-in. to 1-in. diameter, showing mileage from 5000 to 7500, it is recommended that for interurban service an axle of not less than ¾-in. diameter be used.

The necessity of an absolute balance of wheel for high-speed service is emphasized, and as a simple test for balance on commercial wheels it is suggested that wheels to be tested be mounted in harps and the wheel held against a rapidly moving belt. If the balance be even slightly imperfect, it will be found impossible to hold the wheel against the belt. It is not recommended that an extreme type of interurban wheel be used on a city car or *vice versa*, but where a considerable number of both interurban and city cars are operated by the same company it has been found desirable, in some cases, to standardize on the same harp and wheel for all cars; when this is done new wheels are given their first wear on the high-speed interurban cars, and when partly worn and in need of re-bushing are re-bushed and worn out on the city lines.

A different opinion is given by Mr. John Lindall, Superintendent of Rolling Stock and Shops, Boston Elevated Railway Co.: "I do not, however, agree on the suggestion with reference to trolley wheels, that it is economical to increase the life of trolley wheels by using them of large diameter on suburban lines and later transferring them to city lines. From experience on our lines, I am of the opinion that in order to maintain perfect contact between trolley wheel and wire, it is very desirable to make the wheel and outer end of pole as light as possible, and on some of our heaviest and fastest equipment we have been able to obtain better service from a 4-in. wheel than we have from larger wheels of the same composition, and it may not be out of place to call attention at this time to the desirability of having a certain amount of spring in the trolley pole where this can be obtained without interference with trolley wire at low points, as a pole with considerable spring will absorb shocks and more readily respond to inequalities (both vertical and horizontal) in wire."

Life of Trolley Wheels. The trolley wheel of the Indianapolis Traction and Terminal Co. is 6 in. in diameter. The hub is 1¾ in. long, 1½ in. in diameter and the bore is ⅞ in. Its composition is 88 per cent. copper, 10 per cent. tin and 2 per cent. of a trade fluxing material. Its life varies from an average of about 4200 miles in high speed interurban service on 45-ton cars equipped with four 90-h.p. motors geared for a maximum speed of 60 miles per hour up to 21,000 miles in city service on 20-ton cars equipped with two 60-h.p. motors geared for a maximum speed of 27 miles per hour. Mr. Charles A. Ingle, Electric Railway Journal, 1914, states as follows: "For the past year the Rockford & Interurban Railway, Rockford, Ill., has been able to average approximately 10,000 miles on its trolley wheels by getting the maximum possible wear out of them. We use a 6-in., 4-lb. wheel with a ⅞-in. hollow shaft, for which we pay $1.05. The new wheels are installed in interurban service, and as they wear down are transferred to city car until worn out. We had much trouble at first because the hub would become badly worn before the rim. Now when this occurs we bore out the hub 1⅛ in. scant and press in a ⅞-in. inside diameter, 1⅛-in. outside diameter phosphor-bronze bushing, which is swaged at both ends with a tapered pin (1/16 in. taper to fit). This makes the bushing tight in the wheel and allows it to run freely on the ⅞-in. axle. At a cost of

7 cents for labor and material we frequently obtain from 3000 to 4000 miles additional life from a wheel, and in all cases we attain the limit of wear." Other companies report wear varying from 2800 miles in interurban service to 25,000 or 30,000 miles in city service.

Trolley Defects. The following brief consideration of possible defects in trolley wheels is from a paper by Mr. C. W. Squier, Electric Railway Journal, 1914: The greatest trouble with trolley wheels arises from the difficulty of securing satisfactory lubrication and of conducting the current from the wheel to the harp. Some of the most frequent defects are as follows: sides bent, broken or chipped; double groove; holes in sides; flat spots; bushing hole too large; burned wheels; sides loose and rim worn off.

Bent, Broken or Chipped Sides. Bent, broken or chipped sides usually result from wheels coming off the wire and striking some part of the overhead construction. The number of such troubles can be reduced by proper attention to the lubrication of the trolley stands so as to insure their free swiveling, by making sure that the wheels stand perpendicular to the car roof so as to make proper contact with the trolley wire, by keeping the side bearings properly adjusted so as to prevent the swaying of the car when operating at high speeds, by renewing the trolley bushings and axles before they become unevenly or excessively worn, and by keeping the trolley tension properly adjusted.

Double Grooves or Holes in Sides. Double grooves or holes in the sides arise from the condition that the wheel is not following the wire properly, and this may be due to improper maintenance of the overhead construction. These defects also occur frequently on cars that are operated from one end on lines with frequent curves, caused by the wire riding the flange while rounding a curve. If the harps are not straight in the poles so that the wheel is maintained at an angle to the wire, or if the side springs are weaker on one side of the car than on the other so that the car body does not rest level when loaded, the trolley wheels are liable to wear unevenly. When a wheel is found wearing to one side it can be made to wear straight in some cases by reversing it in the harp.

Flat Spots. Flat spots are caused by the sliding of the wheel on the wire on account of imperfect rotation. Flanges frequently become slightly bent and rub against the harp, or the side springs and washers may be too tight or exert too great pressure against the side of the wheel. Flat spots usually start with a very slight slippage between the wheel and the wire, but when a spot is once started it increases rapidly.

Bushing Hole too Large. Over-sized bushing holes are caused by lack of lubrication or by shunts and springs which have become so worn and loose that their pressure is too light to properly conduct the current to the harp. A slight burning or pitting results from the carriage of the excessive current through the bearing and axle. This causes the bushing to bind on the axle, and if it is not a very tight fit in the wheel, rotation will take place around the bushing instead of the axle. Under such circumstances only a few trips are required to wear out the bushing hole in the wheel.

Burned Wheels and Sleet Troubles. Burned wheels are caused when the wheel becomes separated short distances from the wire so that rapid arcing and destructive burning take place. Sleet destroys the wheel very rapidly in this manner. At other times it is found that if a wheel is out of balance its centrifugal force as it rotates will break the contact with the wire. The trolley tension on cars found with burned wheels should always be tested carefully. In sections where sleet storms are frequent, sleet cutters are used to advantage. On large systems, however, the removal of trolley wheels and the installation of sleet cutters assume enormous proportions and come as an additional task for the shop forces at the very time when they are usually busy with snow equipment. Large city roads usually prefer to depend on the frequency of the service to keep the sleet off the wire, or they install sleet cutters on but a few cars of each line, depending on these to scrape the ice clean and thus prevent excessive burning on the wheels of the other cars.

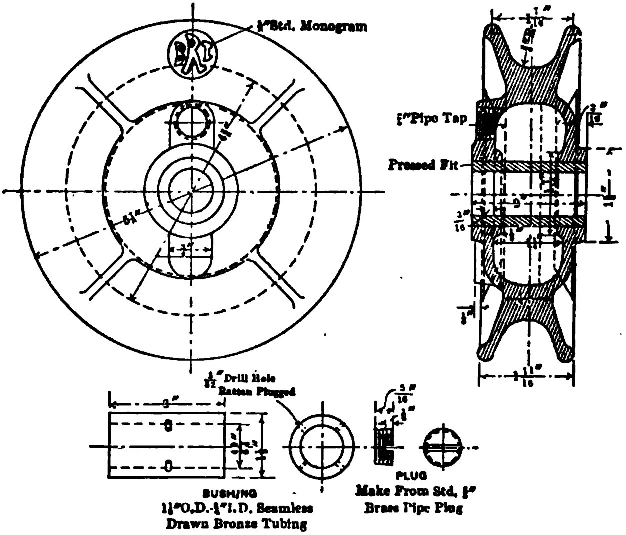


FIG. 1.—Trolley wheel, Brooklyn elevated lines.

Sides Loose and Rim Worn Off. Loosened sides and worn rims are troubles experienced with built-up wheels such as those with steel flanges and a copper center, and they usually are due to the construction of the wheel. Their number can be decreased by the treatment prescribed in the paragraph on "*double grooves or holes in sides.*"

Trolley Wheel and Harp Details. Figs. 1, 2 and 3 give the details of standard trolley wheels and harps used by the Brooklyn Rapid Transit System.

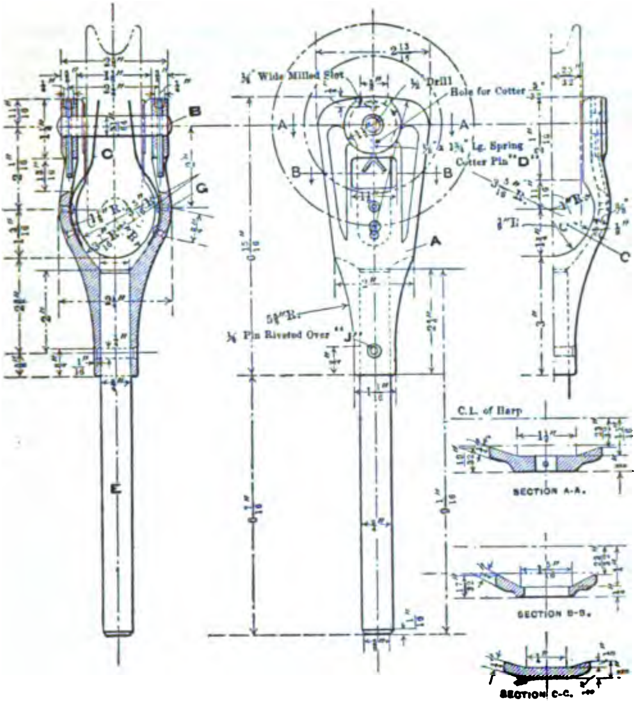


FIG. 2.—Trolley harp, Brooklyn surface lines.

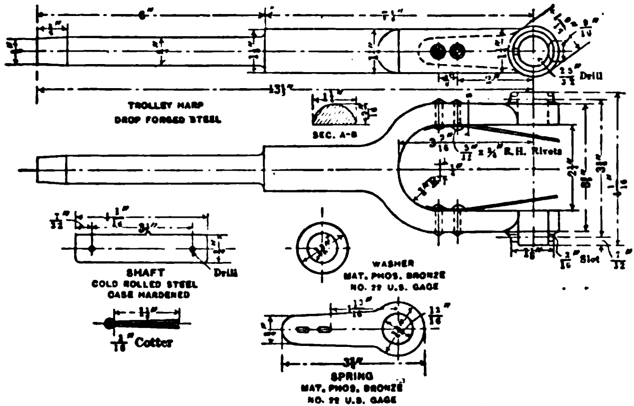


FIG. 3.—Trolley harp, Brooklyn elevated lines.

Current Carrying Capacity of Trolley Wheel. The following values of current carrying capacities of trolley wheels when traveling at various speeds are from the Standard Handbook for Electrical Engineers. The pressure between trolley wheel and trolley is assumed to vary from 20 to 40 lb.

Speed, miles per hr........	5	10	20	30	40	50	60
Current capacity, amperes.	1000	850	650	550	400	300	200

Trolley Base. The functions of a trolley base are to provide so flexible a support for the trolley pole that it will have free movement both laterally and vertically while exerting the pressure necessary to keep the trolley wheel in contact with the wire. A freely swiveling base is most essential in order that the trolley wheel may follow the overhead line. To provide this extreme sensitiveness, roller and ball-bearing bases have come into general use. Both types operate satisfactorily when provided with properly hardened parts. By using ball bearings a lower base can be obtained than with roller bearings, but on the other hand roller bearings give greater wearing surfaces. Various pressure spring arrangements are in use. Some bases have springs in tension and others have springs in compression. Further, some bases have but a single spring, while others have a battery of springs. The following brief consideration of possible trolley base defects is from a paper by Mr. C. W. Squier, Electric Railway Journal, 1914:

Broken or Weak Springs. A spring which is in tension breaks most frequently at the end loops or at the bend where the loop joins the first turn of the spring. The number of such breakages can be reduced by keeping the parts over which the springs hook in good condition so that the loops have a maximum amount of bearing surface. By the use of a magnifying glass one may often discern small cracks in new springs at the bend from the loop to the first turn of the spring. These cracks are evidently due to the method of manufacture, and while such springs are strong enough to withstand heavy strains, they will ultimately break at these fissures. Springs are also weakened from the gradual loss of their ability to resist elongation or to the compression which follows the slow accumulation of a permanent set. In older types of bases the full power of the springs may not be available for producing tension at the trolley pole because of excessive friction in such parts as the cross-pin that forms the up-and-down bearing for the trolley pole, the cross-head in its guide, the side rod bearings which carry the trolley spring pressure and the trolley springs themselves on their guides. It is very difficult to keep these parts lubricated, as rain forces the oil out on the roof of the car and the windows and sills often become bespattered and soiled from oil. In the later designs of stands an effort has been made to provide bearings which do away with the necessity for constant oiling at friction points, and the designers have also endeavored to provide for a uniform pressure of the trolley wheel on the wire at different elevations. Tension springs are sometimes weakened by overstretching them during installation. One bad practice, for example, is to force a screw-driver or other sharp tool between the spirals of the spring and to use this as a lever to hook the eye over its post. This is likely to force the spirals apart to such a distance that they will not come back to their original position.

Worn Bearings and Pins. Worn bearings at various parts of the base are a constant source of trouble. In a great many cases the desire to keep down the weight has left insufficient material to permit the boring and bushing of worn bearings. Some roads have gone to the expense of making patterns of new castings which are provided with sufficient material to allow all wearing parts to be bushed. Fig. 4 illustrates one method of bushing a yoke to take care of excessive wear.

Nut, Bolt, Ball and Roller Troubles. All nuts should have lock washers, and if difficulty is then experienced, cotter keys should be added. Where ball bearings are used, the races are usually insulated from the socket casting to prevent them from carrying the trolley current. Notwithstanding this precaution, the frequent discovery of burned ball races and balls shows that they do carry current. This action may take place in several different ways. For instance, the contact shunts that carry the current from the socket casting to the base plate occasionally get bent out of position so that they bear on the race and socket casting at the same time. Current then passes across the contact face of the shunt to the ball race and thence through the balls to the base plate, causing the burning of the balls and race. Moisture and dirt collect on the surface of the insulation, and the current then has an easy path to the ball race. Again, contact shunts are sometimes torn off entirely and current then passes over the surface of the insulation from the socket casting to the race. When new ball races are installed care should be taken to see that the lower edge of the ball race does not project beyond or come flush with the contact surface of the socket casting. This precaution will prevent the contact shunts from bearing on the race, for then they cannot touch the edge of the race while still remaining in contact with the face of the socket casting.

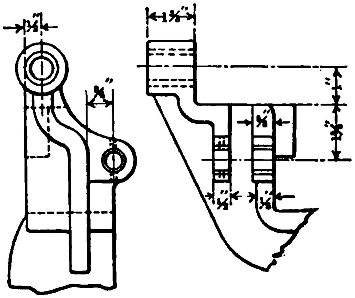


FIG. 4.—Bushings in trolley base yoke.

Burned or Broken Shunts and Burned-off Leads or Terminals. Of necessity, trolley bases must be made very low. As a result, the distance from the socket casting to the base plate is usually not more than 1 to 1¼ in. This, then, is all the space that is available for contact shunts. It is very difficult to get in this space a spring which is efficient enough to give the necessary current-transmitting pressure of the contact shunt against the socket casting. The springs soon take a permanent set and arcing then takes place between the contact surface of the socket casting and the shunt.

As a result, the shunt is burned away or else the contact surface of the socket casting becomes so rough from the arcing that the shunts are torn off. The surface of the socket casting is thus destroyed, and in most cases it is necessary to install a new casting. Fig. 5 shows a brass contact ring which was made to screw to the face of the socket casting. As this ring is of brass, it forms a better conducting surface than the steel casting, and if it becomes burned it can easily be replaced at small expense. This ring also permits the re-use of socket castings that have become slightly burned, since the lower face of the casting can be turned off for the reception of the contact ring. The common form of terminal used on trolley bases consists of a hole in a lug to receive the lead. The hole is provided with set screws to clamp the lead in place. Leads become loose from the working out of the set screws or because the screws are not tightened when a new base is installed. If the screws stay in place, they soon become so rusty that it is almost impossible to remove them when it is necessary to install a new base. If the leads become loose, the arcing thereby initiated soon burns away the lead and terminal. A better form of terminal which can be quickly and easily removed consists of a standard soldered terminal such as is used for the ground leads on motors. If the trolley lead is soldered into this properly, there is no danger that the lead will burn off at this place. This terminal is then bolted to the base plate, where a spot-finished surface is provided to give a good contact surface.

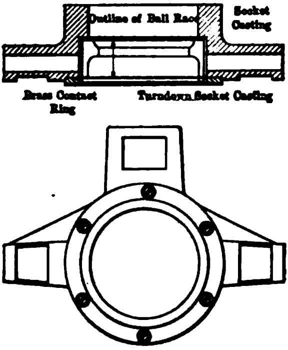


Fig. 5.—Trolley base with contact ring.

Inspection and Lubrication of Trolley Wheel, Stand, Rope and Retriever. (A.E.R.E.A. Miscellaneous Methods and Practices)

Examine wheel and see that bushing and hub or spindle are not unduly worn and that outer rims are not bent, nicked or worn out; see that cotter keys holding spindle in harp are in good condition; see that contact springs and washers are sufficiently tight between harp and hub of wheel to form a good contact, but not so tight as to allow the wheel to slide on the wire. See that the spindle is tight enough in the harp to form a good contact, and that the spindle holes in the harp are not too badly worn to prevent this contact. Examine the harp and see that it is not loose on the pole and that rivets holding same are tight. Examine pole for cracks, bends or flaws, and see that it alines the wheel properly with the wire, and if not, loosen the clamp bolts and turn with a pipe wrench until wheel is in proper alinement, leaving the wheel on the wire during the operation. See that clamp bolt and nut holding same and base bolts are all tight and in good condition; examine springs and see that they have sufficient tension, allowing sufficient space between the coils for compression when the pole is pulled down to the roof of the car. In bases with more than one spring, see that they are equalized on each side, both sides given the same tension. Give springs sufficient tension so that the wheel will have pressure of about 20 to 25 lb. against the wire in city service and from 35 to 40 lb. on high speed. Make this test where the wire is of standard height. It can be done by using a hook scale, or by hanging an old brake-shoe or other weight to the trolley rope. See that trolley board is securely fastened to the roof of the car.

Trolley Lubrication. Lubricate trolley wheels at each inspection and wipe all surplus oil from wheel hub after lubricating. Lubricate bases when necessary. This can be determined by swinging the pole from side to side below the wire. If the base operates freely no lubrication is necessary. Great care must be taken not to allow any surplus oil or grease to reach car roof while lubricating the bases and wheels.

Trolley Rope. See that rope has a firm fastening with the harp; that it is not chafed or showing signs of wear where it comes in contact with the hood; that it has not been broken and that is has no unnecessary knots in it.

Trolley Retriever. Trip the retriever and see if it operates properly; that the tension in the retriever spring is not so severe as to break the rope or pull the trolley down so severely as to damage the hood or roof; see that rope works freely when resetting, and that it is of such length that it will not pull trolley from the wire where the wire is high, such as at railroad crossings, etc.

Extra Trolley Pole. See that all interurban cars are supplied with an extra pole, fully equipped, and in good condition.

Trolley Pole and Pressure between Trolley Wire and Trolley Wheel. Poles of such length that the longitudinal axis of the pole makes an angle of from 35 to 45 deg. with the axis of the trolley on tangent track are in most common use and the most common length is 12 ft. Height of car, height of trolley wire, alinement of track and other local conditions may require a longer or shorter pole between the limits 10 ft. and 14½ ft. A light flexible pole is preferable to a heavy one, as it adapts itself to irregularities in the overhead system and does comparatively little damage to that system when the trolley wheel jumps from the trolley wire. The pressure between trolley wire and trolley wheel should be such that the trolley wheel will follow the trolley wire with as little wear as possible. High-speed service requires a greater pressure than low-speed service. When the proper pressure has been decided upon, the adjustment should be made by measurement. This adjustment has been commonly made by hanging a weight at the end of the trolley pole or by fastening a spring balance to the trolley rope and applying the required tension through the spring balance, then adjusting the trolley stand spring till the wheel is of the proper height to just touch the trolley wire. Adjustment by use of the weight has been found to be the most satisfactory.

In operating practice, pressure between the trolley wheel and wire varies from 16 to 40 lb., pressures from 16 to 25 lb. being usually considered sufficient for city operation, while 35 lb. is generally used in high-speed interurban operation. As the alinement of trolley wire and condition of track approaches perfection, the trolley wheel pressure approaches the minimum, and no more pressure should be used than is required to hold the trolley on the wire at the required speeds with properly lubricated trolley bases.

Trolley Poles for Double-truck Cars. The general practice is to use two trolley poles on double-truck cars, the trolley base usually being mounted directly over the center of the truck, although less offset in trolley wire is required when the trolley base is mounted between the truck center and the end of the car. With two trolley poles there is less likelihood of the trolley wheel being pulled off the wire from rope friction over the rear end of the car or a defective retriever; with two trolleys the car is not entirely disabled by the failure of one; trolley wheel replacements are made more easily when the base is located nearer one end of the car; and the offset required in trolley wire on curves is less as the trolley base is brought nearer the car end. With short double-truck cars in city service, where the distance between truck centers is not great, and the trolley wheel may be easily observed from the rear platform, a single trolley pole may be used to advantage.

Third Rail Collector. The third rail collector has the greatest current collecting capacity of any current collecting device used in electric railway work. In the section on electric traction by Mr. A. H. Armstrong, Standard Handbook for Electrical Engineers, it is stated that tests have been made which indicate that electricity may be collected at the rate of 2000 amperes from a single shoe at a speed of 35 miles per hour and 500 amperes at a speed of 70 miles per hour. The two general classes of collectors are that in which the contact pressure is furnished by gravity and that in which the contact pressure is furnished by a spring. The shoes are generally made of wrought iron or cast iron and in some cases a steel wearing surface is used.

Fig. 6 shows the details of the third rail collector designed for operation on overrunning protected third rail in the New York subway. Contact pressure is furnished by a spring. The shoe is arranged with a stop by which its downward movement is limited. The maximum possible drop is 1½ in., but this may be reduced by shims. Connection from the shoe to the supporting brackets is made by a flexible cable wound around the shaft. The cable is wound in this way so that it will not be affected by the motion of the shoe.

Fig. 7 shows the automatic third rail collector for use on overrunning third rail of the Philadelphia and Western Ry. The pressure between third rail and slipper is about 10 lb. and is furnished by a spring which also serves to hold the shoe in the inoperative position. A tool-steel insert in the slipper is used for the wearing piece. This piece is held in place by two rivets and babbitt. During the winter the slipper is slanted slightly downward in order to make contact with the far side of the third rail, as this part of the rail is usually free from sleet. This slanting is done by means of

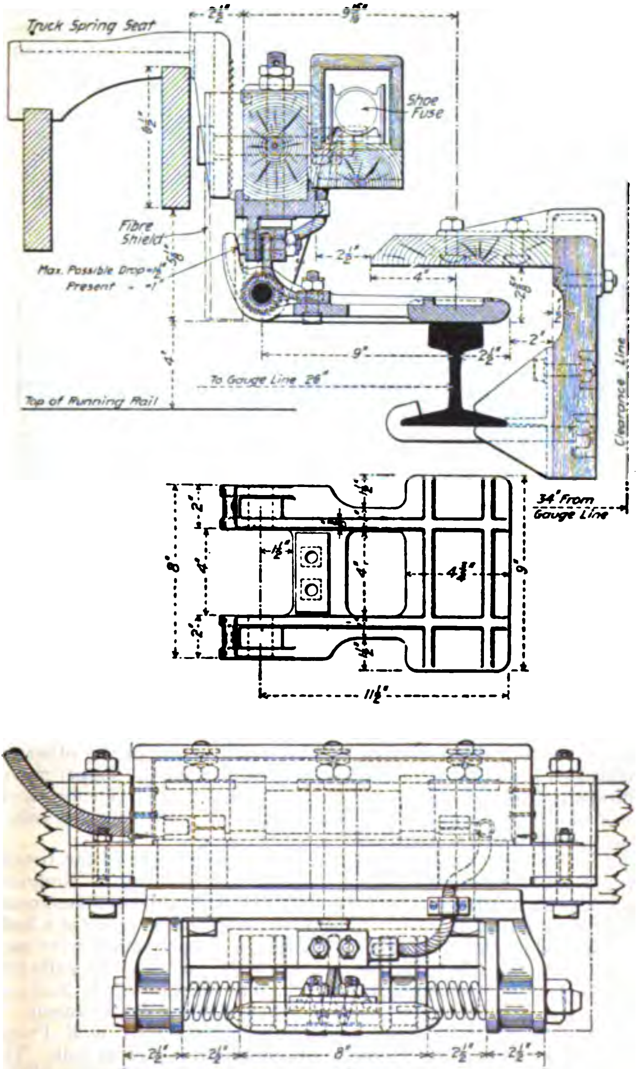


FIG. 6.—Third rail collector, New York subway.

the eccentric stop, the four quarter turns of which will also take care of a 1.5-in. reduction in diameter of the car wheels. There is also a rack adjustment on the car trucks for raising and lowering the collector beams. The automatic folding and unfolding of the shoe is obtained in the following manner: Where the shoes should either open or fold, as the case may be, two parallel metal strips which are sloped in opposite directions are placed along the tracks and set several inches apart. If the shoe is open, the slipper will bear against the rising strip until it assumes a nearly vertical position, and the spring then acts to close it. The rising of the slipper, however, is coincident with the lowering of a tail-piece which is always at right angles to the slipper. When the shoe is to be opened, this tail-piece will be within range of the other inclined strip, so that it will be forced upward while the slipper moves downward to make contact with the conductor rail. The eccentric stop and the tail-piece prevent the slipper from dropping when unsupported by the third rail.

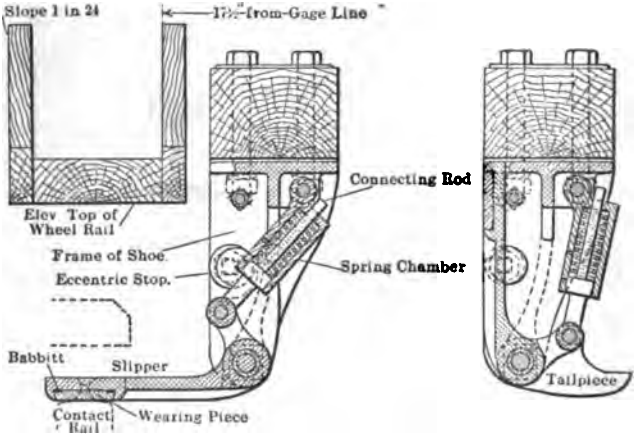


Fig. 7.—Third rail collector, Philadelphia and Western.

Fig. 8 shows a third rail collector and sleet brush of the Brooklyn Rapid Transit Co. This collector was designed to eliminate all links and castings, it is of wrought iron, and it allows a maximum height variation of 2.5 in. The wrought iron shoe replaces a link-suspended casting which was too fragile. Copper shunts were used on the casting, but the flat springs were found to be sufficient conductors on the type illustrated. The sleet brush is made of No. 23 B. & S. gage wire, which is renewed about every season.

Fig. 9 shows a third rail collector patented by Mr. R. R. Potter for use with either overrunning or underrunning third rail. The tension or pressure of the shoe on the rail is regulated by the position of the spring in relation to the pivot or bearing points and may be set at any reasonable amount. If the spring is placed back of the line of bearing, the outer end of the shoe is caused to rise, and it then becomes suitable for use on an underrunning rail. In case both an underrunning and overrunning shoe is desired, two pivot points are used. No machine work is necessary, no lubrication is required and no shunts are used.

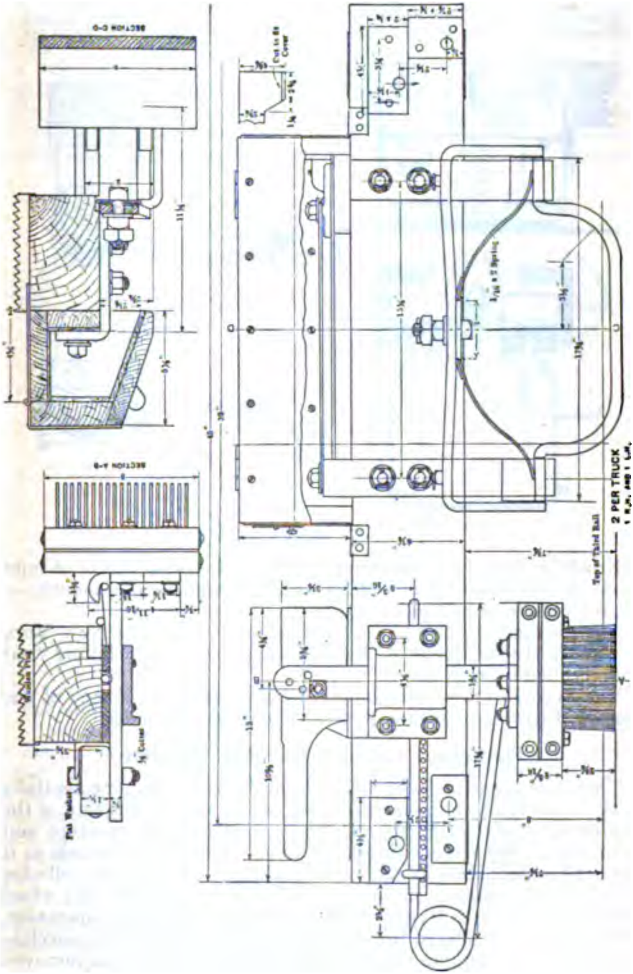


FIG. 8.—Third rail collector and sleet brush, Brooklyn.

Life of Third Rail Contact Shoe. Overrunning gravity type of third rail contact shoe of the Interborough Rapid Transit Co. for the year 1907 was as follows:

	Subway	Elevated
Average life, contact shoe-miles	45,720	56,008
Average cost per 1000 contact shoe-miles	$0.02322	$0.01241

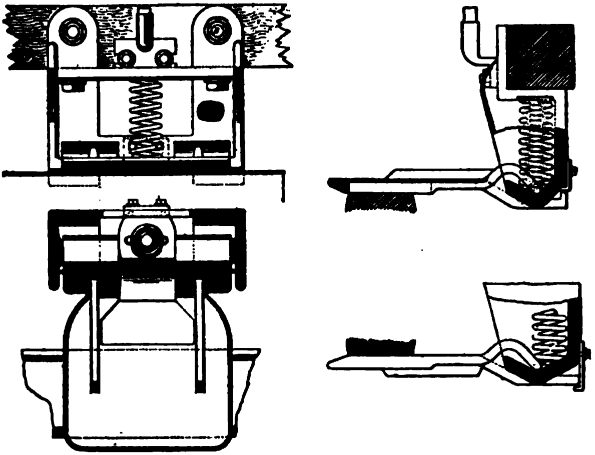


FIG. 9.—Third rail collector for either over- or underrunning.

Brooklyn Rapid Transit System third rail contact shoe of mild steel 5/16 in. thick and 8 in. wide gives an average life of 9 months or approximately 31,000 miles.

The average life of a third rail contact shoe on the New York Central & Hudson River R. R. is about 3600 miles (including wear and accidental breakage).

The average life of the third rail cast-steel contact shoe of the Aurora, Elgin and Chicago R. R. is about 100,000 miles.

Pantograph Collector and Bow Collector

The pantograph collector differs from the bow collector essentially in the movement and position of the contact shoe. The shoe of the pantograph collector is controlled by a pantograph structure and moves in a vertical plane through the center of the mechanism as it rises and is depressed in action, while the shoe of the bow collector is trailed in a manner similar to that of the common trolley wheel and moves in a vertical curve. When used in high voltage operation, both types are insulated from the car by being mounted on porcelain insulators. Both types are generally placed in action and removed therefrom by means of a compressed air mechanism and in high voltage service this is often arranged to automatically lower the collector when the high voltage distributing box is opened. The scheme of the pneumatic operation of the low pantograph on New York Central locomotives is diagrammed in Fig. 10. Near each master controller in the cab there is a valve by means of which the pantograph shoe may be raised or lowered. When air is applied, the shoe is lifted so as to make contact with the overhead rail. When air is released, the shoe drops; also if the shoe runs off the rail, it is tripped automatically and drops. Moving the handle forward operates the pilot valve, by means of which a slide-valve is thrown to admit air from the reservoir to the cylinder of the contact shoe device. Pulling the handle back operates another pilot valve and the slide-valve is thrown over to connect the air chamber of the contact device to the exhaust. The handle will spring back to the middle position from either direction. There are two of these overhead contact shoes which are controlled in common by either valve in the cab.

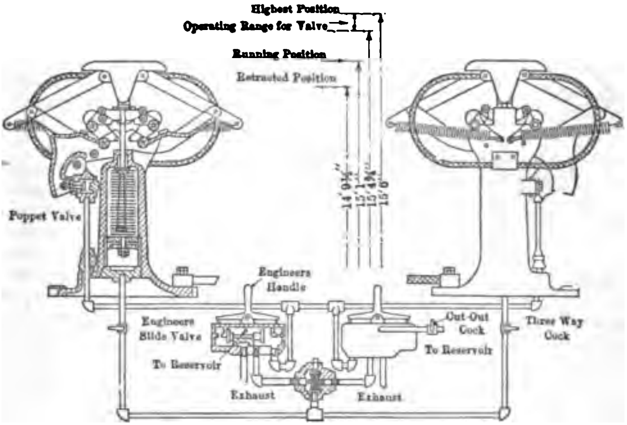


FIG. 10.—Low pantograph collector, New York Central.

Either pantograph or bow may be used when high speed, voltage or amperage or overhead construction will not permit satisfactory wheel trolley operation. In many places a pantograph is used in suburban service, but in city service the overhead construction permits only a wheel trolley. This is provided for by equipping each car with a pantograph in the middle and a wheel trolley pole at each end. A typical pantograph collector is shown by Fig. 11. Both the pantograph collector and the bow collector are built with many variations in the details of construction. The pantograph collector is built with either the simple pantograph and rigid contactor or with the pantograph base to follow great changes in trolley wire height and having the contactor spring-supported to follow minor unevenness. The bow collector may have a framework or pole or a pantograph base to follow variations in trolley wire height and from this the contactor is generally carried on a lighter secondary trailing structure made flexible to follow minor unevenness. The following, relative to successful current collector operation, is by Mr. Otis Allen Kenyon, Elec. Ry. Journal, 1909:

The successful operation of any system depends upon the ability of the contactor to keep in contact with the wire. Failure to do this produces arcing and hammering. The arcing destroys both the collector shoe and the wire, while the hammering accelerates the wear, kinks the wire and breaks the fastenings. The difficulty of keeping the collector in contact with the wire increases very rapidly with the speed, and the minimizing of this difficulty is one of the important problems in high speed operation. The variations in the position of the wire over the track, and the swaying of the car require the collecting device to be so constructed as to adapt itself to all such variations, thus forming a flexible connection between the wire and the car. At low speeds it is comparatively easy to design such a device, since all variations in position take place so slowly that the inertia of the collector does not prevent it from following the wire. However, at high speeds the effect of every little variation is exaggerated and tends to produce vibration. Large variations in position, such as are caused by passing under bridges, etc., when made gradually, have little or no effect on vibration. The three principal causes of vibration are:

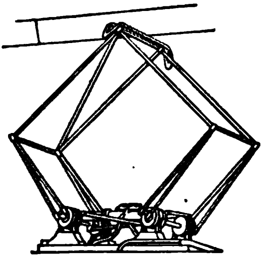


FIG. 11.—Typical pantograph collector.

(1) Unevenness of the contact wire, due either to imperfect suspension or non-uniform wear.

(2) Vibration and swaying of the car or locomotive.

(3) Inertia of the contact device.

The results of experiments made thus far (1909) seem to point to a type of collector which should consist of two parts, namely, a main part to take up the large variations in the height of the wire and an auxiliary part to take up the vibrations. The main part may be comparatively large and heavy and should be balanced for wind pressure and provided with springs arranged to exert a constant pressure irrespective of the position of the shoe. The auxiliary part, which should trail, must be light and designed to have a high natural period of vibration which will enable it to follow the most rapid vibrations of the car to which it will be subjected.

Contact Shoe. Contact shoes have been made of copper, steel, aluminum and various alloys in attempts to get a considerable life of shoe together with small wear on the trolley wire. A shoe of "U" shaped section containing lubricant in the form of grease has been found to reduce wear and singing. Aluminum shoes are light, consequently they have comparatively little inertia which makes possible a collector structure of high natural period of vibration.

Contact Shoe Wear. The following, relative to contact shoe ear, is by Mr. Otis Allen Kenyon, Elec. Ry. Journal, 1909:

Wear of the wire and shoe can be traced to two causes, mechanical and electrical. The mechanical causes are due to pressure and cannot be entirely eliminated. Non-uniformity of pressure is the most serious trouble. The springs can be so designed as to make the pressure constant for any position of the collector. However, the speed at which the collector changes its position affects the pressure to an extent which can only be controlled by reducing the inertia of the mass to be moved. Throughout Europe the average pressure of the contact shoe against the wire is about 11 lb. The electrical causes are secondary, being due to arcing, which is caused by insufficient contact surface. Arcing is especially destructive in that once started the surface is left more predisposed to arcing than before and conditions rapidly go from bad to worse. The cause is due to imperfect contact and vibration and the resulting wear is a function of the current rather than of the power. For a given power the lighter the voltage the less destructive is the arc. Soot deposited on the contact wire by steam locomotives increases the wear to an astounding extent. The Swedish commission found that the wear of the shoe on a soot-covered wire is about ten times as rapid as on a clean one. The aluminum shoes on the other types of collectors ran about 1500 miles on soot-covered wires. It is estimated in the report that on clean wires they would run at least 12,500 miles. The practice of the Swedish tramways indicates an average life of such shoes, when used in tramway service, of 12,500 miles before renewal, but if left until worn out they will run as high as 62,000 miles.

In tests on the New Haven electrification, Mr. W. S. Murray found that a pantograph shoe supported on spiral springs had a considerably longer life than one rigidly supported. In a paper, A.I.E.E., 1908, he stated that the cost for pantograph shoe was about 0.06 cent per locomotive mile. This was for the rigid shoe and represents approximately 2 per cent. of the total cost of maintenance and repairs per locomotive per locomotive mile. He also noted that where soot was present, mileages varying between 600 and 1500 per shoe had been obtained, while roads operating lesser speeds and not subject to the effects of locomotive stack discharges, had obtained as high as 25,000 shoe miles.

A galvanized sheet-steel pantograph shoe is used on the locomotives operating in the St. Clair Tunnel of the Grand Trunk Railway System. The average life of one of these shoes is 3000 miles. The pressure used is 7.5 lb. in winter and 5 lb. in summer. The speed is 25 miles per hour. A shoe with a copper wearing surface was found to have a much shorter life than the steel shoe. The steel shoe did not wear the copper trolley wire so much as the copper shoe did.

On the New York, Westchester and Boston Ry. galvanized iron pantograph shoes 1/16 in. thick were replaced by black mild-steel shoes of the same thickness. The life of the black-steel shoe is 2600 miles. The normal pressure is 10 lb. for both winter and summer. During spring and fall it is 14 lb. to 15 lb. It was noted in 1913 that after this road had operated for about 1½ years the life of a pantograph shoe was about four times as great as at the beginning. Mr. R. R. Potter attributes this increase in life to the fact that the original cross-section of the steel contact wire of the catenary system was circular while the wear during this period had produced a flat contact surface about 1/8 in. wide.

Roller Trolley. The roller trolley is second to the third rail shoe in current collecting capacity, but it has more inertia than the pantograph shoe. For these reasons it is suited to service at heavier currents and at lower speeds than those to which the pantograph shoe is particularly adapted. Fig. 12 shows a roller trolley used successfully on the Key Route, California. The roller is mounted on a pantograph frame and weighs, complete with spindle, 28 lb.

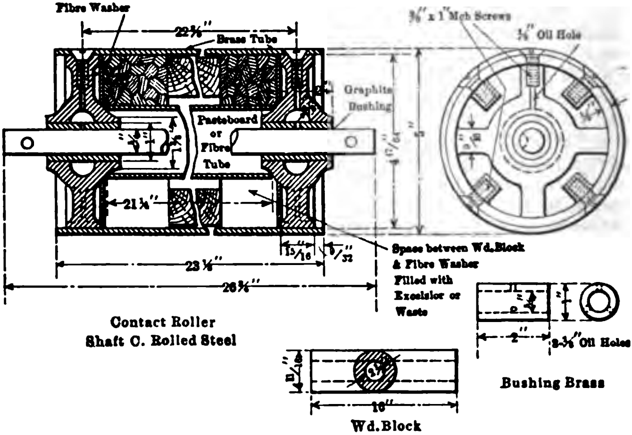


FIG. 12.—Roller trolley, Key Route, California.

The wearing surface is a tube of non-arcing brass, supported on a wooden roller. The height of the trolley wire above the head of the rail varies from 14 ft. 6 in. to 22 ft., but by the pantograph the pressure of the roller against the wire is kept nearly constant at about 34 lb. The average mileage of the rollers is 55,000.

Top Contact Collector (Oerlikon Collector). Current is collected from either a trolley wire suspended from an inverted catenary or a trolley wire stretched tightly over insulators at the side of the track. The collector consists essentially of a curved hinged arm which sweeps over nearly a semicircle in a plane transverse to the longitudinal axis of the track. This collector is supported on insulators on the side of the car top. Normally the arm rests on top of the trolley wire with a pressure of about 1.5 lb. On cross-overs and in tunnels, where the trolley wire is carried over the track, the arm swings toward the center of the car, and is depressed, making contact progressively from the top around to the side and then underneath the trolley wire. In addition, the saddle which carries the arm is movable laterally, increasing the radius of action.

Slot Plow. The slot plow is arranged to collect current from conductor bars which are located about 6 in. apart and a foot below the track rails. It consists of a flat frame made of insulating material suspended from the car and carrying the necessary conductors from the conductor bar to the car. This frame extends through the ⅝-in. or ¾-in. slot between the slot rails and carries a contact shoe at either side of its lower end. It insulates the contact shoes from each other. The contact shoe is generally made of

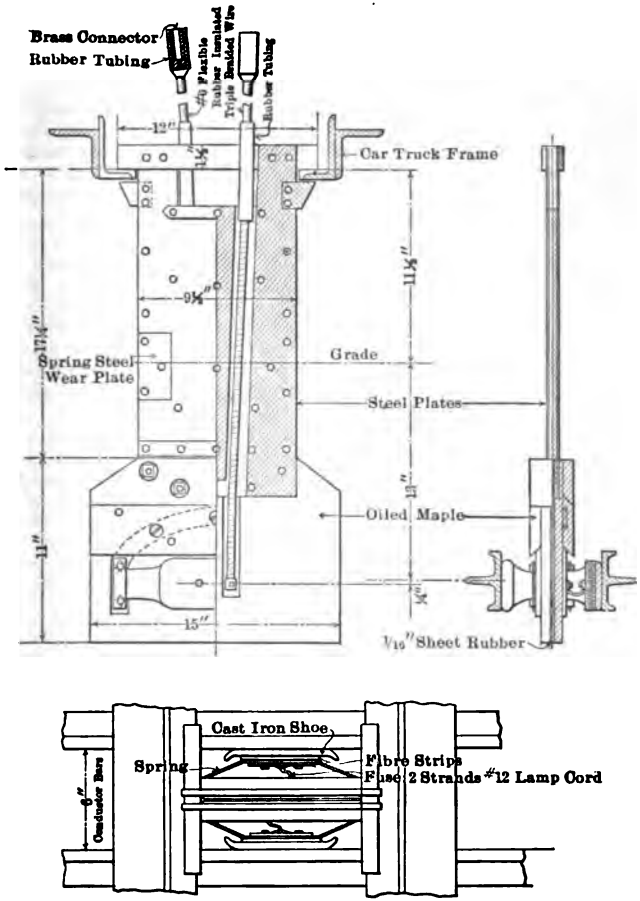


Fig. 13.—Slot plow, Washington.

chilled cast iron and is held against the conductor bar by a flat steel spring by which it is fastened to the frame. The frame carries thin wear plates of hard steel for protection against excessive wear in rubbing over the slot rails. Electrical connection between the contact shoes and the upper end of the plow is by fuse connectors and rubber-insulated conductors. These fuse connectors are connected to the contact shoes and serve to protect the plow from damage by short circuit from shoe to shoe. Fig. 13 shows a slot plow used by the Capital Traction Co., Washington, D. C. The suspension of the plow from the truck must admit of free lateral movement in order that the plow may not be damaged by truck play and unevenness of track and slot rails. Where the car moves between a conduit section and a trolley section, the plow is removed or replaced by a man stationed in a pit at the junction of the two sections.

SECTION VII

TRUCKS

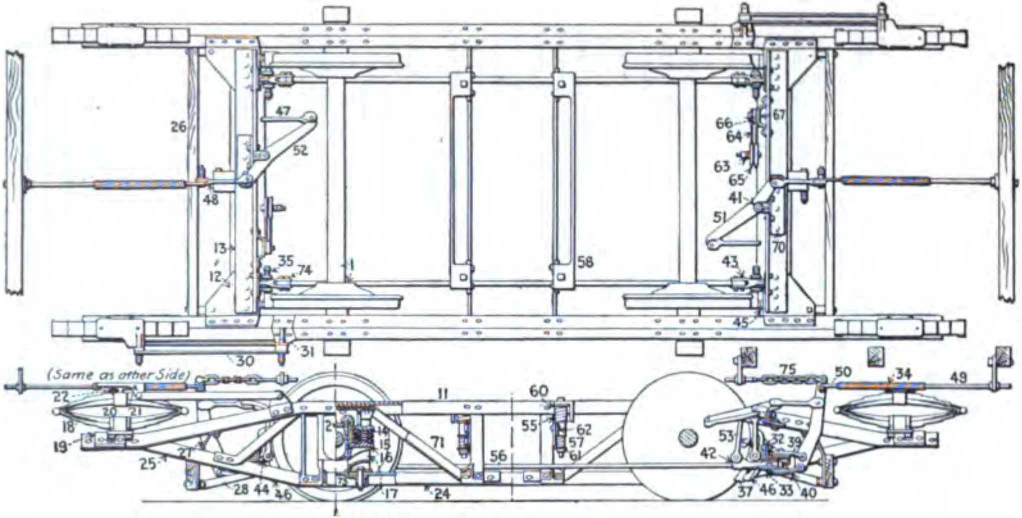
General Classification. Trucks are of two general classes, namely, the single truck and the double truck. The latter is also often called the swivel truck or the bogie truck.

Single Trucks. (Figs. 1 to 5.) Single trucks are of two classes, namely, parallel axle trucks and radial axle or non-parallel axle trucks. The length of wheel base of the truck is limited by track curvature. The radial axle truck (Figs. 3 to 5) was developed to make possible a comparatively long wheel base giving satisfactory operation on curves.

Radial Axle Truck. Fig. 3 shows the Warner radial axle truck. Fig. 4 shows the Brill radial axle truck, and Fig. 16 shows the swing link of this truck when it is in the normal (vertical) and extreme positions, respectively. When this truck is on tangent track and the link is in an upright position, the truck frame rests upon both the pins at the lower end of the link. At the instant the wheels strike an irregularity in the track, one of these pins leaves its groove and, due to the resulting displacement of the link, there is a force tending to return the link to the upright position and to draw the axle back to its normal position on leaving the irregularity. Fig. 5 shows a radial axle truck on a low level type car to take 24-in. wheels and "dachshund" motors. This truck is built for low level end drop platform cars and is provided with ball bearings.

Double Trucks. (Figs. 6 to 15.) Double trucks may be classified as fixed bolster trucks or swing bolster trucks. The fixed bolster truck is one in which the truck bolster is fixed to the side frame so that there is no relative motion between them. The swing bolster truck is one in which the truck bolster may move relatively to the side frame of the truck. The swing bolster truck is better suited to high-speed service than the fixed bolster truck and it is generally used on passenger cars. In the M.C.B. type, the swing bolster bears on springs that are supported by a transverse member called a spring plank, which is suspended by hangers or links so that it can swing laterally to the truck. As the springs rest on this plank and they support the bolster, the latter can swing with the spring plank. Other types of swing bolster trucks have been developed, modified in some respects from that described above, but accomplishing the same results. The object of providing the swinging motion to the bolster is to prevent, as much as possible, lateral blows and shocks from being communicated to the car body and, *vice versa*, to prevent the momentum of the car body from acting with its full force on the truck and track.

Maximum Traction Truck. (Figs. 13 to 15.) The maximum traction (single-motor) truck is suited to moderate speed service



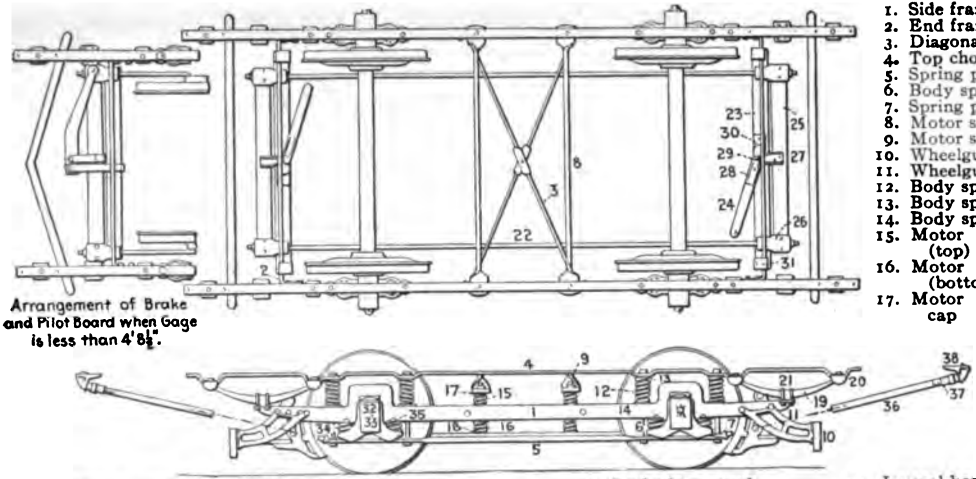
Names of Parts

2. Journal box
11. Side frame
12. Side and end frame gusset
13. End frame
14. Equalizer springs
17. Pedestal
18. Elliptic spring
24. Side frame horizontal truss
25. Side frame diagonal truss
26. Fender board
28. Fender board brace
30. Car body anchor link
32. Brake beam
33. Brake equalizer
34. Brake release spring
39. Brake beam fulcrum
40. Brake equalizer fulcrum
41. Brake lever fulcrum
47. Top brake rod
51. Brake lever (live)
52. Brake lever (dead)
55, 57. Motor spring
56. Bottom brake rods
58. Motor bar
60, 61. Motor spring caps
70. End frame stiffener
71. Side frame brace
73. Pedestal spreader
75. Stop chain

FIG. 1.—Standard Motor Truck Co. C-35-A single truck.

Names of Parts

1. Side frame
2. End frame
3. Diagonal brace
4. Top chord
5. Spring post stay
6. Body spring post
7. Spring post stay lug
8. Motor suspension bar
9. Motor suspension bar bolt
10. Wheelguard
11. Wheelguard bracket
12. Body spring
13. Body spring cap
14. Body spring seat
15. Motor suspension spring (top)
16. Motor suspension spring (bottom)
17. Motor suspension spring cap



18. Motor suspension spring seat
19. Body end spring
20. Body end spring cap
21. Body end spring U-bolt
22. Brake rod
23. Brake beam
24. Brake lever
25. Equalizing lever
26. Equalizing lever casting
27. Equalizing lever fulcrum
28. Brake lever casting
29. Brake lever stud
30. Brake beam fulcrum
31. Brake hanger carrier
32. Journal box lid
33. Journal box
34. Journal box spring
35. Journal box spring cap
36. Spring post stay extension adjusting sleeve
37. Spring post stay extension
38. Spring post stay extension adjusting sleeve bearing

FIG. 2.—Brill 21-*E* single truck.

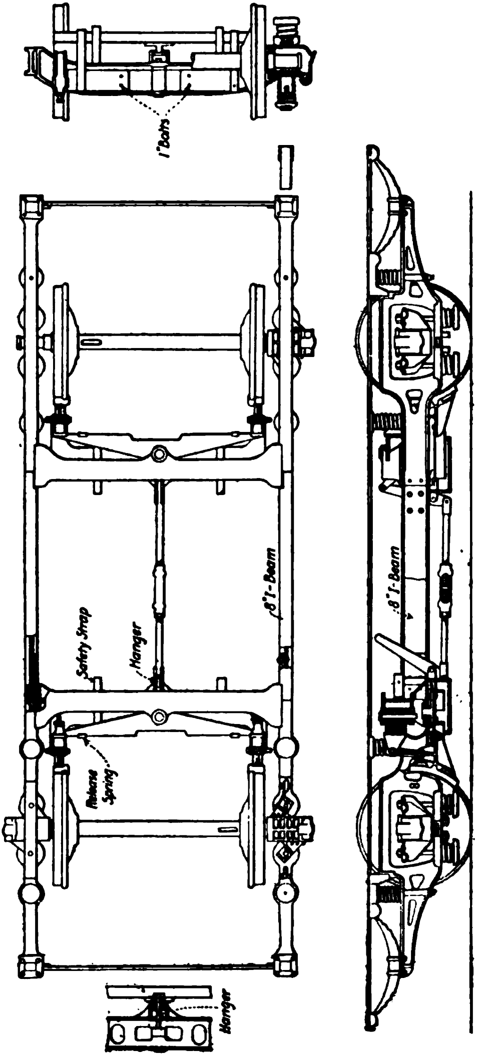
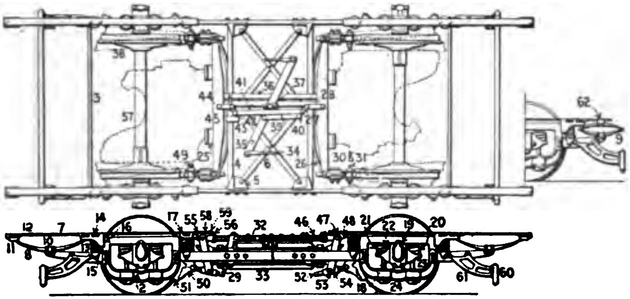


FIG. 3.—Warner radial axle truck.



Names of Parts

1. Side frame
2. Yoke brace
3. End frame pipe and tie rod
4. Cross bar
5. Cross bar corner bracket
6. Cross bar brace
7. Top chord
8. Body end spring (semi-elliptic)
9. Body end spring (full elliptic)
10. Body end spring U-bolt
11. Body end spring cap (half-elliptic)
12. Body end spring wear plate
13. Body spring (coil)
14. Body spring bolt
15. Body spring seat
16. Thrust piece
17. Body spring cap
18. Journal box
19. Journal box lid
20. Journal box spring
21. Journal box spring cap
22. Swing link socket
23. Swing link
24. Swing link pin
25. Motor suspension bracket
26. Motor suspension casting
27. Cross bar brace casting
28. King bolt reinforcing plate
29. King bolt
30. Brake hanger spring top
31. Brake hanger spring bottom
32. King bolt support (top)
33. King bolt support (bottom)
34. Brake rod
35. Center lever
36. Center lever slide
37. Center lever fulcrum
38. Wheel
39. Center lever connection
40. Live lever
41. Lever connection
42. Dead lever
43. Dead lever fulcrum
44. Top truck connection
45. Equalizing beam
46. Clevis
47. Upright lever
48. Brake hanger carrier
49. Brake hanger, "half-ball"
50. Brake head
51. Brake shoe
52. Bottom truck connection
53. Bottom truck connection jam nut
54. Bottom truck connection trunnion
55. Release spring
56. Release spring bracket
57. Axle
58. Release spring hook bolt
59. Release spring hook bolt nut
60. Wheelguard
61. Wheelguard bracket
62. Body end spring cap (full elliptic)

FIG. 4.—Brill "Radiax" truck.

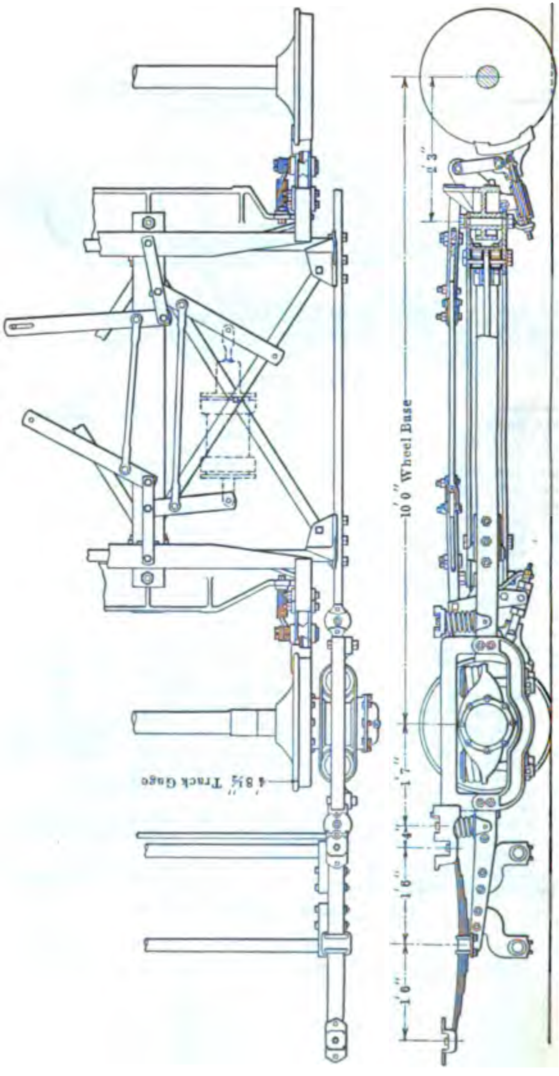
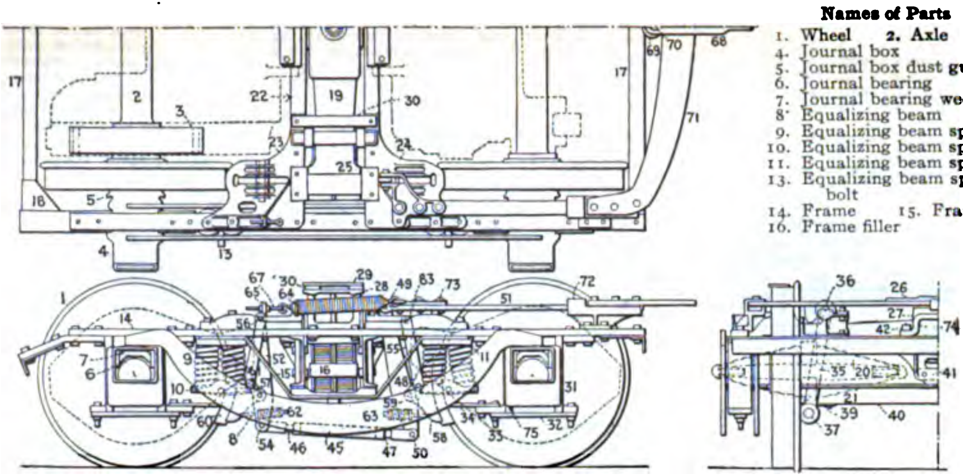


FIG. 5.—Radial axle truck with ball bearings and 24-in. wheels for low level drop platform car. (Third Ave. Ry., N. Y.)



Names of Parts

1. Wheel 2. Axle 3. Gear
4. Journal box
5. Journal box dust guard
6. Journal bearing
7. Journal bearing wedge
8. Equalizing beam
9. Equalizing beam spring
10. Equalizing beam spring seat
11. Equalizing beam spring cap
13. Equalizing beam spring seat bolt
14. Frame 15. Frame truss
16. Frame filler

17. End frame
28. End frame gusset
19. Bolster
10. Bolster spring 22. Transom
23, 24. Transom gussets
25. Transom chafing plate
26. Carbody center plate
27. Truck center plate
28. Side bearing

29. Side bearing plate
30. Side bearing shims
31. Pedestals 32. Pedestal cap
33. Pedestal cap bolt and nut
34. Pedestal brace
35. Swing link
39. Swing link pin bearing
40. Spring plank
41. Motor suspension bracket

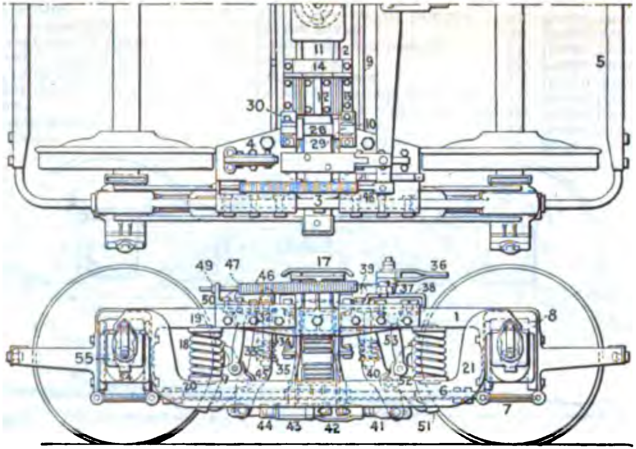
42. Motor suspension bolt
45. Brake turnbuckles
48. Brake live lever
51. Brake live lever rod
52. Brake dead lever
55. Brake hanger
58. Brake head
60. Brake shoe
61. Brake shoe key

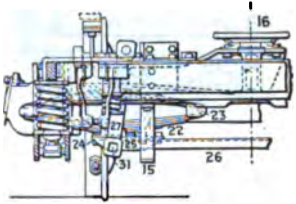
62. Brake shoe adjusting spring
64. Brake release spring
68. Brake pull rod jaw
69. Brake pull rod roller
71. Radial brake beam
72. Radial brake beam guide
73. Brake live lever rod jaw
74. Motor suspension strap
75. Pedestal gib

FIG. 6.—Baldwin Locomotive Works type A double truck.

Names of Parts

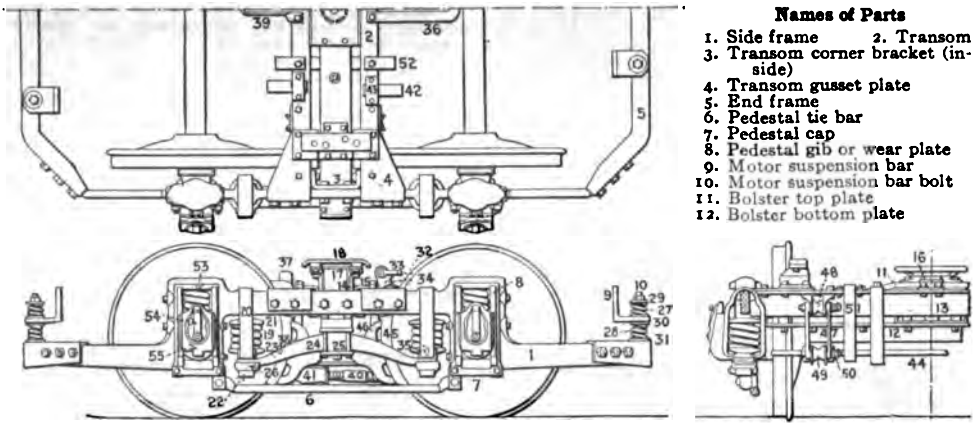
1. Side frame 2. Transom
3. Transom corner bracket
4. Transom gusset plate
5. End frame
6. Pedestal tie bar
7. Pedestal cap
8. Pedestal gib or wear plate
9. Motor suspension bar
10. Motor suspension bar bolt
11. Bolster
12. Bolster chafing plate
13. Transom chafing plate
14. Transom tie bar





15. Spring plank safety hanger
16. Truck center plate
17. Side bearing wear plate
18. Equalizer spring
19. Equalizer spring cap
20. Equalizer spring seat
21. Equalizer or equalizing bar
22. Bolster spring scroll
24. Bolster spring seat
25. Bolster spring seat rocker
26. Spring plank
27. Swing link or bolster hanger
28. Swing link pin (top)
29. Swing link pin pivot
30. Swing link pin bearing
31. Swing link pin (bottom)
32, 33. Motor suspension springs
34. Motor suspension spring cap
35. Motor suspension spring seat
36. Brake rod
37. Radius bar
38. Radius bar guide
39. Radius bar clevis
40. Live lever
41. Brake turnbuckle end
42. Brake turnbuckle
43. Brake turnbuckle lock
44. Brake turnbuckle lock spring
45. Dead lever
46. Brake release spring
47. Brake release spring casting (location indicated)
48. Brake release spring hook bolt
49. Brake release spring nut
51. Brake shoe
52. Brake head
53. Brake hanger
54. Journal box
55. Journal box lid.

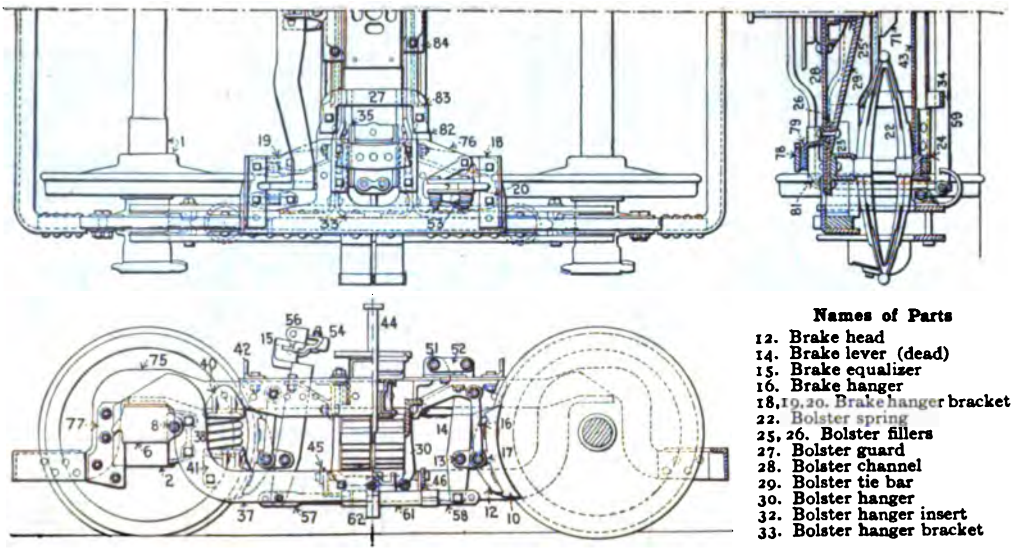
FIG. 7.—Brill 27-M.C.B double truck.



Names of Parts

1. Side frame 2. Transom
3. Transom corner bracket (inside)
4. Transom gusset plate
5. End frame
6. Pedestal tie bar
7. Pedestal cap
8. Pedestal gib or wear plate
9. Motor suspension bar
10. Motor suspension bar bolt
11. Bolster top plate
12. Bolster bottom plate
13. Bolster filling casting
14. Bolster chafing plate
15. Transom chafing plate
16. Truck center plate
17. Side bearing
18. Side bearing wear plate
19. Equalizer spring
20. Equalizer spring link
21. Equalizer spring cap
22. Equalizer spring bolt
23. Equalizer spring seat
24. Bolster spring
25. Bolster spring seat
26. Bolster spring seat rocker
27, 28. Motor suspension springs
29. Motor suspension spring cap
30, 31. Motor suspension spring seats
32. Brake rod
33. Brake rod clevis
34. Live lever
35. Live lever fulcrum
36. Live lever guide
37. Dead lever
38. Dead lever fulcrum
39. Dead lever guide
40. Bottom truck connection
41. Bottom truck connection jaw
42. Brake release spring
43. Brake release spring clip
44. Brake beam
45. Brake shoe 46. Brake head
47. Brake hanger
48, 49. Brake hanger carriers
50. Brake hanger spring cap
51. Brake hanger spring
52. Brake beam safety hanger
53. Journal box spring
54. Journal box lid
55. Journal box

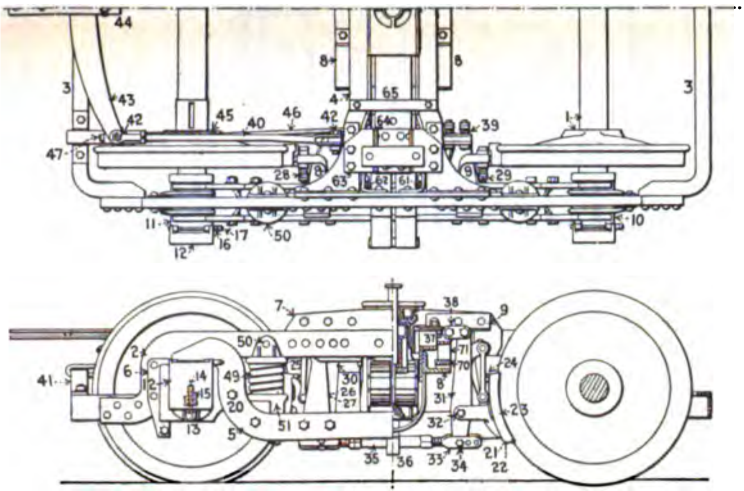
FIG. 8.—Brill 27-G double truck.



Names of Parts

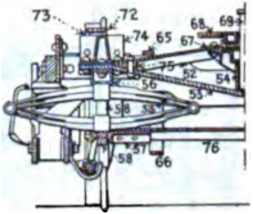
12. Brake head
14. Brake lever (dead)
15. Brake equalizer
16. Brake hanger
18, 19, 20. Brake hanger bracket
22. Bolster spring
25, 26. Bolster fillers
27. Bolster guard
28. Bolster channel
29. Bolster tie bar
30. Bolster hanger
32. Bolster hanger insert
33. Bolster hanger bracket
34. Bolster safety strap
37. Equalizer bar
38, 39. Equalizer spring
43. Spring plank 44. King pin
45. Equalizer tie bar
47. Release spring
51. Dead lever fulcrum
52. Dead lever link
53. Dead lever guide spring
54. Top brake rod connection
57, 58. Bottom brake rod
61. Turnbuckle
62. Turnbuckle safety strap
63. Fender board
64. Fender board bracket
65, 66. Life guards
74. End frame 75. Side frame
78. Side bearing
81. Side bearing filler
82. Transom
83. Transom stiffener
84. Motor support wear plate
86. Motor support
87. Motor bar

FIG. 9.—Standard Motor Truck Co. C-55 depressed frame double truck.



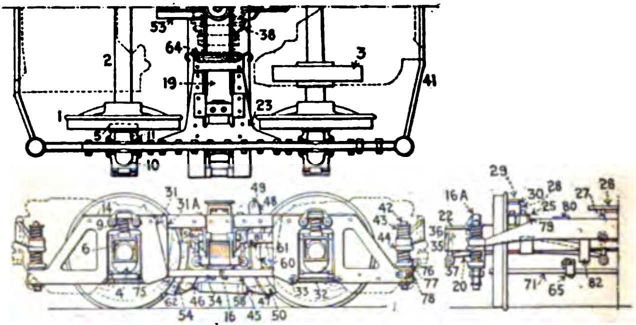
Names of Parts

2. Side frame
3. End frame
4. Transom
5. Equalizer bar
6. Side frame wear piece
7. Side frame stiffener
8. Transom stiffener
9. Transom gusset
21. Brake head
23. Brake shoe
24. Brake shoe key
25. Brake hanger
26. Brake hanger bracket
28. Brake hanger spring



31. Brake lever
33. Bottom brake rod jaw
34. Bottom brake rod bolt
35. Turnbuckle
36. Turnbuckle safety strap
37. Dead lever fulcrum
38. Dead lever links
39. Dead lever guide springs
40. Top brake rod
41. Top brake rod support
43. Brake equalizer
45. Release spring
48. Release spring holder
49. Equalizer spring
52. Bolster channel
53. Bolster tie bar
54. Bolster center filler
55. Bolster spring
58. Bolster hanger
61. Bolster hanger bracket
63. Bolster hanger bracket wear plate
64. Bolster wear plate
65. Bolster guard
66. Bolster safety strap
67. Truck center plate
68. Body center plate
69. King pin
70. Motor support
71. Motor guard
72. Side bearing
73. Side bearing shim
74. Side bearing filler
75. Bolster filler
76. Spring plank

Fig. 10.—Standard Motor Truck Co. C-60 double truck.



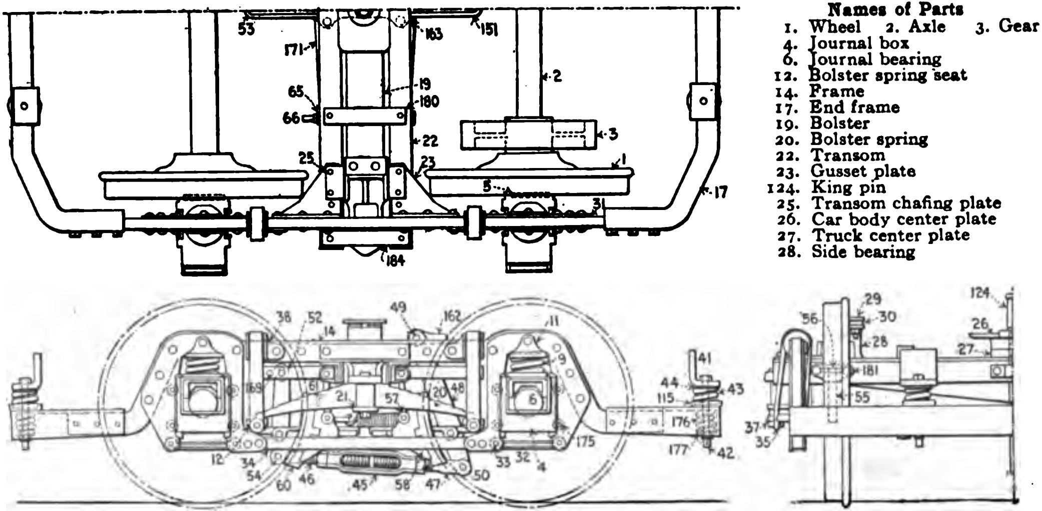
Names of Parts

1. Wheel
2. Axle
3. Gear
4. Journal box
5. Journal box dust guard
6. Journal bearing
9. Journal box spring
10. Journal box spring seat outside
11. Journal box spring seat inside
14. Frame
16. Frame filling bottom
16a. Frame filling, top
19. Bolster
20. Bolster spring
22. Transom
23. Gusset plate
25. Transom chafing plate
26. Carbody center plate
27. Truck center plate
28. Side bearing
29. Side bearing plate
30. Side bearing shims
31. Pedestal, inside
31a. Pedestal, outside
32. Pedestal cap
33. Pedestal cap bolt and nut
34. Pedestal brace
35. Swing link
36. Swing link pin, top
37. Swing link pin, bottom
38. Swing link pin bearing, top
41. Motor suspension bar
42. Motor suspension bolt
43. Motor suspension spring, top
44. Motor suspension spring washer, top
45. Brake turnbuckle
46. Brake turnbuckle rod, R. H. thread
47. Brake turnbuckle rod, L. H. thread
48. Brake live lever
49. Brake live lever pin, top
50. Brake live lever pin, bottom
52. Brake dead lever
53. Brake dead lever fulcrum
54. Brake dead lever bolt, bottom
55. Brake hanger
56. Brake hanger pin, top
57. Brake hanger pin, bottom
58. Brake head
60. Brake shoe
61. Brake shoe key
65. Brake release spring
65. Brake release spring fulcrum
71. Brake beam
75. Pedestal gibs
76. Motor suspension spring, bottom
77. Motor suspension spring washer, bottom
78. Motor suspension guide
79. Chafing plate filling
80. Transom tie bar
81. Brake hanger bracket
82. Bolster safety strap

FIG. 11.—Baldwin Locomotive Works H-2 double truck.

Names of Parts

1. Wheel 2. Axle 3. Gear
4. Journal box
6. Journal bearing
12. Bolster spring seat
14. Frame
17. End frame
19. Bolster
20. Bolster spring
22. Transom
23. Gusset plate
124. King pin
25. Transom chafing plate
26. Car body center plate
27. Truck center plate
28. Side bearing



29. Side bearing plate
30. Side bearing washers
31. Pedestal
32. Pedestal cap
34. Pedestal brace
35. Swing link
176. Motor suspension spring

53. Brake dead lever fulcrum
38. Swing link bearing
41. Motor suspension knee
42. Motor suspension bolt
43. Motor suspension spring
45. Brake turnbuckle
46. Brake rods R. H. threads

47. Brake rods L. H. threads
48. Brake live lever
151. Brake lever guide
52. Brake dead lever
55. Brake hanger
168. Brake lever fulcrum
64. Brake release spring

170. Brake live lever fulcrum pin
171. Brake beam
175. Pedestal gib
177. Motor suspension washer
180. Transom tie bar
181. Brake hanger brackets
184. Frame filling angle iron

FIG. 12.—Baldwin Locomotive Works, type L double truck.
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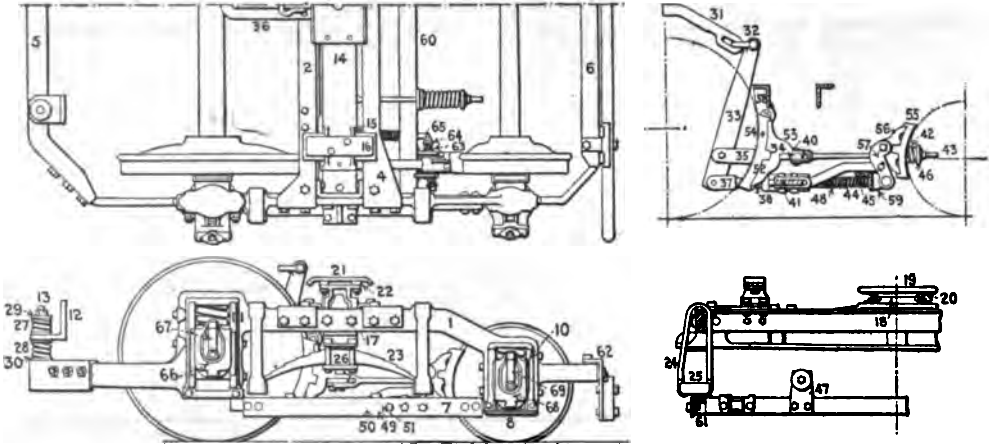
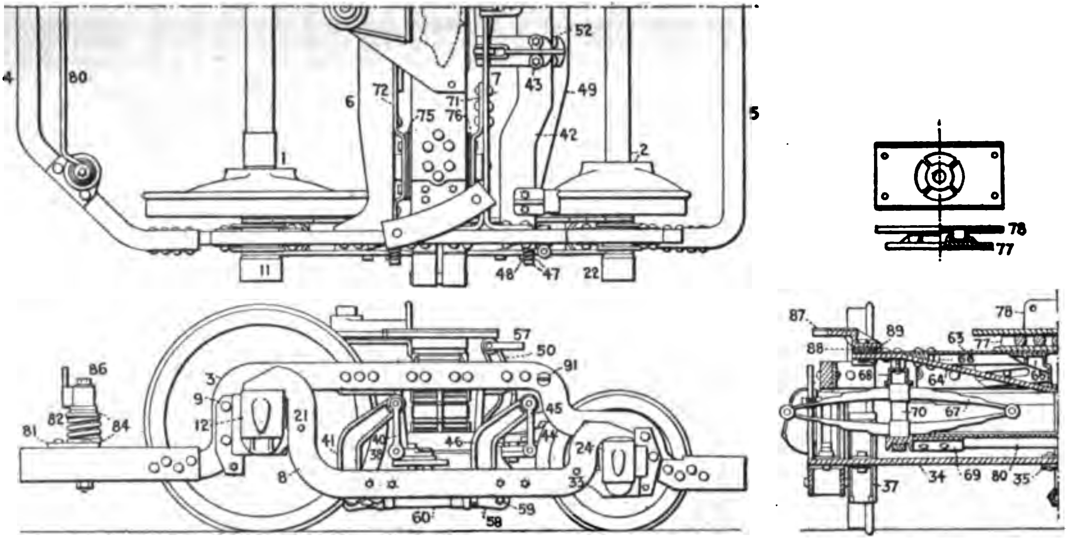


Names of Parts

1. Side frame
2. Transom
3. Double corner bracket
4. Transom gusset plate
5. Motor end crossing
6. Trail end crossing
7. Tie bar. 12. Motor support
14. Bolster
18. Truck bolster pivot plate
19. Body bolster pivot plate
21. Side bearing rub plate
23. Semi-elliptic spring
31. Brake rod stub
33. Upright lever
35. Upright lever fulcrum
36. Upright lever guide
37. Bottom brake rod
38. Bottom brake rod adjusting nut
39. Brake connecting rod
40. Driving wheel brake beam
41. Trail wheel brake beam
42. Driving wheel brake beam release spring
44. Trail wheel brake beam release spring
49. Brake beam slide
52. Driving wheel brake shoe
55. Trail wheel brake shoe
60. Lever support
62. Life guard bracket
63. Brake hanger spring

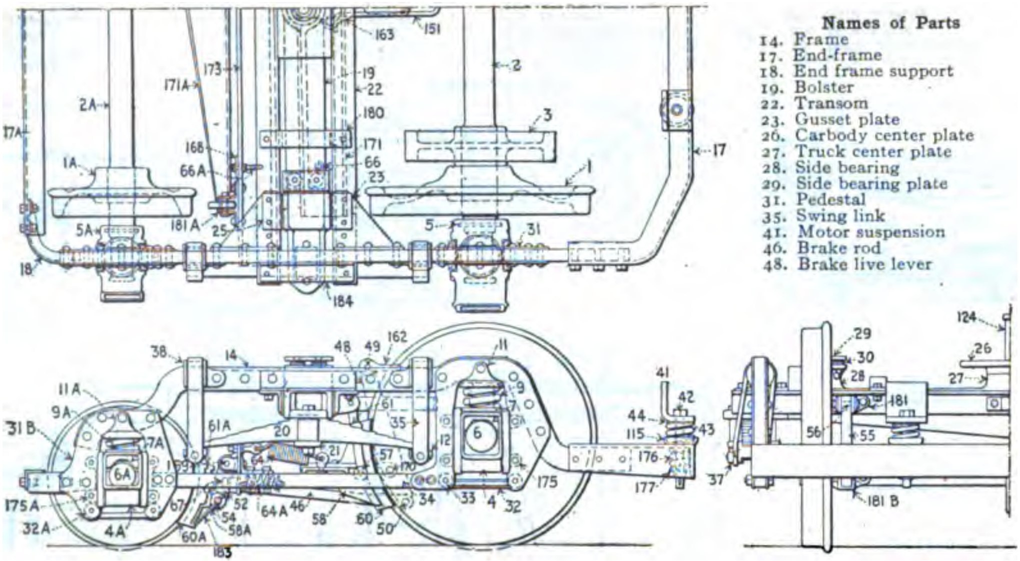
FIG. 13.—Brill 39-E maximum traction truck.



Names of Parts

3. Side frame
4, 5. End frame
7. Transom
8. Equalizer bar
42. Brake beam
49. Floating lever fulcrum beam
50. Brake lever (live)
51. Brake lever (dead)
52. Floating lever fulcrum
53. Dead lever fulcrum
54. Dead lever links
63. Bolster
77. Truck center plate
78. Body center plate
80. Motor bar
87. Side bearing

FIG. 14.—Standard Motor Truck Co. 0-45 maximum traction truck.



Names of Parts

14. Frame
17. End-frame
18. End frame support
19. Bolster
22. Transom
23. Gusset plate
26. Carbody center plate
27. Truck center plate
28. Side bearing
29. Side bearing plate
31. Pedestal
35. Swing link
41. Motor suspension
46. Brake rod
48. Brake live lever

52. Brake dead lever
55. Brake hanger
58. Brake head
60. Brake shoe-driving wheel
162. Brake lever clevis
163. Brake lever fulcrum
64. Brake release spring
67. Brake release spring rod
168. Brake release spring plate
171. Brake beam
173. Brake support angle iron
181. Brake hanger bracket

FIG. 15.—Baldwin Locomotive Works type M maximum traction truck.

where one motor per truck is used and a high value of adhesion between driving wheels and rails is necessary. This truck is so constructed that from 60 to 80 per cent. of the load is carried by the driving wheels on tangent track and a part of this is transferred to the trailing wheels when the truck is on a curve. The driving wheels of the Brill maximum traction truck carry 75 per cent. of the load when on tangent track. When this truck is on a curve a plate attached to the car sills and inclining downward from the center compresses a spring post between the trailing wheels and transfers weight from the driving wheels to the trailing wheels.

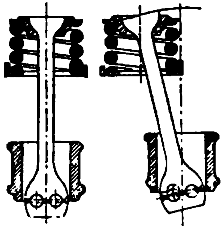


FIG. 16.—Swing link of radiax truck in normal and extreme positions

Truck Parts. There are many different types of motor trucks which have been designed in various ways to meet a great variety of conditions of construction and operation. The names of the important parts of some of these are given by Figs. 1 to 16, inclusive.

Heat-treated Carbon Steel Axles

A heat-treated axle is one which is allowed to cool after forging, is then reheated to proper temperature, quenched in some medium, and then reheated to the proper temperature to refine the grain. The exact treatment of a particular steel depends upon its chemical composition. If the chemical composition of an existing axle be known, the axle may be properly heat treated and then turned down to a smaller size for service. The purpose of heat treatment of axles is to relieve the internal stresses set up by improper cooling, also to so rearrange the structure of the steel that it will resist the action of repeated blows which, though each would have an effect within the endurance of the original untreated steel, such continued repetition would cause the untreated steel to fail by crystallization.

A.E.R.E.A. Standard Specifications for Heat-treated Carbon Steel Axles, Shafts and Similar Parts. (Also adopted as standard by the American Society for Testing Materials.)

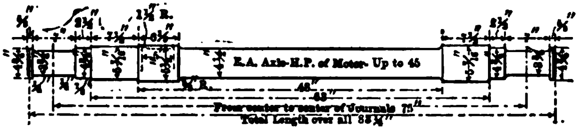
Process of Manufacture: 1. Steel under this specification shall be made by the open-hearth or other approved process.

Discard: 2. A sufficient amount of discard must be made from each ingot to insure freedom from piping and undue segregation.

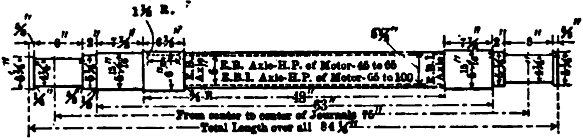
Chemical Compositions: 3. The steel shall conform to the following limits in chemical composition:

Carbon	not over 0.60 per cent.
Manganese	0.40 to 0.80 per cent.
Phosphorus	not over 0.05 per cent.
Sulphur	not over 0.05 per cent.

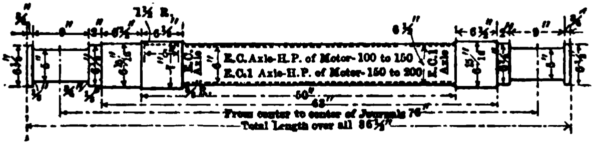
Samples for Chemical Analysis: 4. Drillings shall be taken from the crop end of one axle, shaft or similar part from each melt represented, parallel to the axis on any radius one-half the distance from the center to circumference, to determine whether the chemical composition of the heat is within the limits specified in Paragraph 3. In addition to the complete analysis, the purchaser has a right to call for a phosphorus determination, to be made from the turnings from each tensile test specimen, and the phosphorus must show within the limits called for by Paragraph 3.


1⅛″ R.
E.A. Axle-H.P. of Motor- Up to 45
48″
63″
From center to center of Journals 73″
Total Length over all 83⅜″

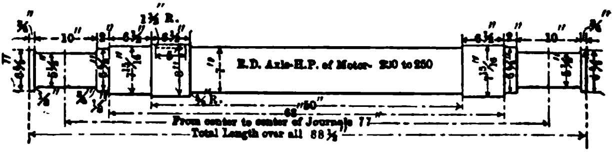
Approx. Wt. 450 lb. Designed to carry 15,000 lb. per axle


1⅛″ R.
E.B. Axle-H.P. of Motor-45 to 65
E.B.1. Axle-H.P. of Motor-65 to 100
49″
63″
From center to center of Journals 76″
Total Length over all 84⅛″

Approx. Wt. E.B. 530 lb. Designed to carry 19,000 lb. per axle
E.B.1. 580 lb. Designed to carry 22,000 lb. per axle


1½ R.
E.C. Axle-H.P. of Motor-100 to 150
E.C.1 Axle-H.P. of Motor-150 to 200
50″
63″
From center to center of Journals 76″
Total Length over all 86⅛″

Approx. Wt. E.C. 750 lb. Designed to carry 27,000 lb. per axle
E.C.1. 820 lb. Designed to carry 31,000 lb. per axle


1⅝″ R.
E.D. Axle-H.P. of Motor- 200 to 250
10″
50″
63″
From center to center of Journals 77″
Total Length over all 88⅛″

Approx. Wt. E.D. 1050 lb. Designed to carry 38,000 lb. per axle

FIG. 17.—A.E.R.E.A. standard motor axles.

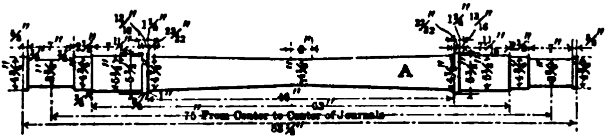
Tensile Test: 5. The steel shall conform to the following minimum physical properties:

Ultimate strength, pounds per square inch	85,000
Elastic limit, pounds per square inch	50,000
Elongation in 2 in., per cent	22
Reduction of area, per cent	45

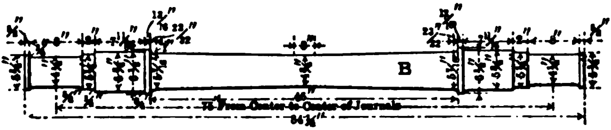
The elastic limit shall be determined by extensometer. Above 40,000 lb. per square inch, each increment of load shall be not more than 1000 lb. per square inch.

Specimen for Tensile Test: 6. The test specimen as shown by Fig. 19, 0.5 in. diameter and 2 in. gage length, shall be used to determine the physical properties as specified in Paragraph 5. Test specimens shall be taken from the crop end of one axle, shaft, or similar part, from each treating-plant heat; if more than one open-hearth heat is represented in a treating-plant heat, a test shall be taken from each open-hearth heat represented. A full-size prolongation shall be left on each axle, shaft, or similar part.

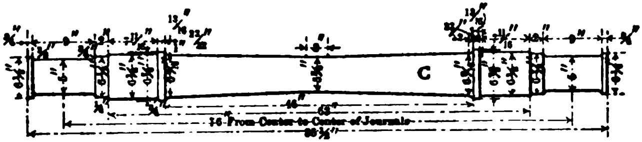
Cold Bend Test: 7. A cold bend test shall be made from the crop end of one axle, shaft, or similar part, from each treating-plant heat; if more than one open-hearth heat is represented in a treating-plant heat, a test shall be taken from each open-hearth heat represented. The test shall be made with a ½ in. square specimen not exceeding 6 in. in length, around a round mandrel, of ½ in. radius, and the specimen shall bend, without fracture 180 deg. around said mandrel.



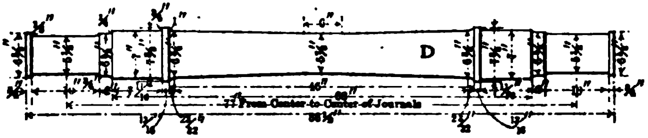
Approx. Wt. 420 lb. Designed to carry 15,000 lb. per axle



Approx. Wt. 520 lb. Designed to carry 22,000 lb. per axle



Approx. Wt. 680 lb Designed to carry 31,000 lb. per axle



Approx. Wt. 830 lb. Designed to carry 38,000 lb. per axle

FIG. 18.—M.C.B. standard axles for trailers.

Explanatory note: The mandrel usually employed is shaped with one side to give a half inch radius as desired while the other side is prolonged to take the thrust of the top head of the testing machine, thus producing a mandrel whose general shape is that of a hammer head with a flat pein, the flat pein of half inch radius to insure proper testing of the piece as "around a half inch radius mandrel" (Fig. 20).

Location of Specimens for Tensile Test and Cold Bend Test: 8. Specimens for tensile test and cold bend test shall be taken parallel to the axis of the axle or shaft and on any radius one-half the distance from the center of the circumference.

Retesting: 9. In case the physical results obtained from any lot of axles, shafts, or similar parts, do not conform to those called for by Paragraphs 5 and 7, the manufacturer shall have the privilege of retreating such parts, from which new tests shall be taken by the purchaser and these shall govern the acceptance or rejection of the lot.

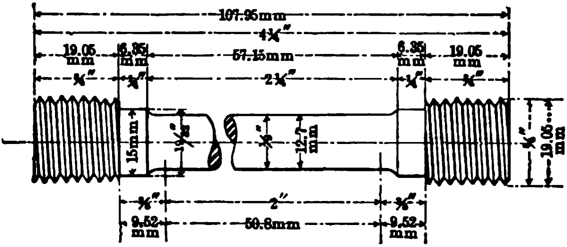


FIG. 19.—A.E.R.E.A. standard tensile test specimen for axle steel.

Heat Treatment: 10. Each axle, shaft, or similar part shall be allowed to become cold after forging, shall then be reheated to the proper temperature, quenched in some medium, allowed to cool, and then reheated to the proper temperature for annealing.

Warped Axles or Shafts: 11. Warped axles or shafts or similar parts must be straightened hot; that is, at a temperature above 900 deg. F., and before offering the part for tests.

Quality: 12. All axles, shafts or similar parts shall be free from cracks, seams, flaws, or other injurious imperfections when finished. Those which show such defects while being finished by the purchaser will be rejected and returned to the manufacturer, who must pay return freight.

Finish: 13. All axles, shafts, and similar parts must be rough-turned with an allowance of ⅛ in. on surface for finishing, except on axle collar, which is to be left rough-forged. Turning must be done on 60-deg. centers with clearance drilled at point.

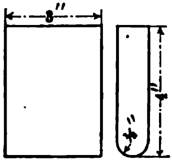


FIG. 20.—Mandrel for cold bend test, axle steel.

Branding: 14. The heat number shall be stamped on the rough-forged collar. After rough-turning, the manufacturer's name, heat number, individual axle or shaft number, and inspector's mark shall be stamped at place indicated by the purchaser except at any point between the rough collars.

Inspection: 15. The inspector representing the purchaser shall have free entry at all times, while his contract is being executed, to all portions of the manufacturer's shop which concerns the manufacture of material ordered. All reasonable facilities shall be afforded to the inspector by the manufacturer to satisfy him that the axles, shafts, and similar parts are being furnished in accordance with the specifications. All tests and inspection shall be made at the place of manufacturer prior to shipment and free of cost to the purchaser. The purchaser shall have the right to make tests to govern the acceptance or rejection in his own test room or elsewhere, as may be decided by the purchaser, such test, however, to be made at the expense of the purchaser and to be made prior to the shipment of the material. Unless otherwise arranged, any protest based on such tests must be made within 6 days, to be valid. Tests and inspection shall be so conducted as not to interfere unnecessarily with the operation of the mill.

Cold Rolled Steel Axles

Specifications for Cold Rolled Steel Axles. (A.E.R.E.A. Recommended Specifications.)

Process of Manufacture: 1. Steel under this specification shall be made by the open-hearth or other approved process. All axles must be cold rolled to finished size from hot rolled bars. Finished sizes must not vary more than two thousandths of an inch above or below the required size.

Discard: 2. A sufficient amount of discard must be made from each ingot to insure freedom from piping and undue segregation.

Chemical Composition: 3. The steel shall conform to the following limits in chemical composition:

Carbon	not over 0.40 per cent.
Manganese	0.40 to 0.80 per cent.
Phosphorus	not over 0.04 per cent.
Sulphur	not over 0.05 per cent.

Samples for Chemical Analysis: 4. Drillings shall be taken from the crop end of one axle from each melt represented, parallel to the axis on any radius one-half the distance from the center to circumference, to determine whether the chemical composition of the heat is within the limits specified in Paragraph 3. In addition to the ladle analysis, the purchaser may have a phosphorus determination made from the turnings or borings taken from each tensile specimen, and the phosphorus in every specimen must be within 25 per cent. of the limit given in Paragraph 3.

Tensile Test: 5. The steel shall conform to the following minimum physical properties:

Ultimate strength, pounds per square inch	70,000
Elastic limit, pounds per square inch	60,000
Elongation in 2 in., per cent	18
Reduction of area, per cent	35

The elastic limit shall be determined by extensometer.

Specimen for Tensile Test: 6. The test specimen, as shown by Fig. 19, 0.5 in. diameter and 2 in. gage length, shall be used to determine the physical properties specified in Paragraph 5. Test specimens shall be taken to represent each 50 axles, or less made from the same melt.

Cold Bend Test: 7. A cold bend test shall be taken from each 50 axles or less, made from the same melt. The test shall be made with ½ in. square specimen, not exceeding 6 in. in length, around a 1 in. flat mandrel having a rounded edge of ½ in. radius (Fig. 20) and the specimen shall bend, without fracture, 180 deg. around the said mandrel.

Location of Specimens for Tensile Test and Cold Bend Test: 8. Specimens for tensile test and cold bend test shall be taken parallel to the axis of the axle and on any radius one-half the distance from the center to the circumference.

Finish: 9. All axles, either finished or plain, shall be straight and free from cracks, flaws, seams or other injurious imperfections when finished. Those which show such defects while being finished by the purchaser will be rejected and returned to the manufacturer who must pay return freight.

Centering: 10. When centering is required, 60-deg. centers with clearance provided at point of shop lathe centers, shall be used unless otherwise specified.

Branding: 11. Each axle shall be stamped with the heat number, maker's brand and year. Unless otherwise indicated these marks are to be stamped at about the middle of the length of the axle. The manufacturer shall also permit the inspector to place his stamp on each axle.

Inspection: 12. The inspector representing the purchaser shall have free entry, at all times while his contract is being executed, to all portions of the manufacturer's shop which concerns the manufacture of material ordered. All reasonable facilities shall be afforded to the inspector by the manufacturer to satisfy him that the axles are being furnished in accordance with the specifications. All tests and inspection shall be made at the place of manufacture prior to shipment and free of cost to the purchaser. The purchaser shall have the right to make tests to govern the acceptance or rejection in his own test room, or elsewhere, as may be decided by the purchaser, such test, however, to be made at the expense of the purchaser and to be made prior to the shipment of the material. Unless otherwise arranged, any protest based on such inspection must be made within 6 days, to be valid. Tests and inspection shall be so conducted as not to interfere unnecessarily with the operation of the mill.

Annealed Carbon Steel Axles

Specifications for Annealed Carbon Steel Axles, Shafts and Similar Parts. (A.E.R.E.A. Recommended Specification.)

Process of Manufacture: 1. Steel under this specification shall be made by the open-hearth or other approved process.

Discard: 2. A sufficient amount of discard must be made from each ingot to insure freedom from piping and undue segregation.

Chemical Composition: 3. The steel shall conform to the following limits in chemical composition:

Carbon	not over 0.60 per cent.
Manganese	0.40 to 0.60 per cent.
Phosphorus	not over 0.04 per cent.
Sulphur	not over 0.05 per cent.

Samples for Chemical Analysis: 4. Drillings shall be taken from the crop end of one axle, shaft, or similar part from each melt represented, parallel to the axis on any radius one-half the distance from the center to circumference, to determine whether the chemical composition of the heat is within the limits specified in Paragraph 3. In addition to the complete analysis the purchaser may have a phosphorus determination made from turnings or borings taken from each tensile test specimen and the phosphorus in every specimen must not be more than 25 per cent. above the limit given in Paragraph 3.

Tensile Test: 5. The steel shall conform to the following minimum physical properties:

Ultimate strength, per square inch	80,000 lb.
Elastic limit	44,000 lb.
Elongation in 2 in., per cent	22
Reduction of area, per cent	35

Elastic limit shall be determined by extensometer.

Specimen for Tensile Test: 6. The test specimen, as shown by Fig. 19, 0.5 in. diameter and 2 in. gage length, shall be used to determine the physical properties as specified in Paragraph 5. Test specimens shall be taken from the crop end of one axle, shaft, or similar part, from each annealed heat; if more than one open-hearth heat is represented in the annealed heat, a test is to be taken from each open-hearth heat represented. A full-size prolongation shall be left on each axle, shaft, or similar part.

Cold Bend Test: 7. A cold bend test shall be made from the crop end of one axle, shaft, or similar part from each heat; if more than one open-hearth heat is represented in a heat, a test shall be taken from each open-hearth heat represented. The test shall be made with a ½ in. square specimen not exceeding 6 in. in length, around a 1-in. flat mandrel, having a rounded edge of ½ in. radius, and the specimen shall bend without fracture 180 deg. around said mandrel. The test shall be made by steady pressure or by blows. The form and dimensions of the mandrel are shown in Fig. 20.

Location of Specimens for Tensile Test and Cold Bend Test: 8. Specimens for tensile test and cold bend test shall be taken parallel to the axis of the axle or shaft and on any radius one-half the distance from the center to the circumference.

Re-testing: 9. In case the physical results obtained from any lot of axles, shafts, or similar parts do not conform to those called for by Paragraphs 5 and 7, the manufacturer shall have the privilege of re-annealing such parts, from which new tests shall be taken by the purchaser, and these shall govern the acceptance or rejection of the lot.

Annealing: 10. Each axle, shaft, or similar parts shall be allowed to become cold after forging, shall then be re-heated to the proper temperature for annealing, allowed to cool slowly (in furnace) in an approved manner.

Warped Axles or Shafts: 11. Warped axles or shafts or similar parts must be straightened hot; that is, at a temperature above 900 deg. F., and before offering the parts for test.

Quality: 12. All axles, shafts, and similar parts shall be free from cracks, flaws, seams, or other injurious imperfections when finished. Those which show such defects while being finished by the purchaser will be rejected and returned to the manufacturer, who must pay return freight.

Finish: 13. All axles, shafts, and similar parts must be rough-turned with an allowance of ⅛ in. on surface for finishing, except on axle collars, which are to be left rough-forged. Turning must be done on 60-deg. centers with clearance drilled at point.

Branding: 14. The heat number shall be stamped on the rough-forged collar. After rough-turning, the manufacturer's name, heat number, individual axle or shaft, and inspector's mark shall be stamped at a place indicated by the purchaser, except at any point between the rough collars.

Inspection: 15. The inspector representing the purchaser shall have free entry, at all times while his contract is being executed, to all portions of the manufacturer's shop which concerns the manufacture of material ordered. All reasonable facilities shall be afforded to the inspector by the manufacturer to satisfy him that the axles, shafts and similar parts are being furnished in accordance with the specifications. All tests and inspection shall be made at the place of manufacture prior to shipment and free of cost to the purchaser. The purchaser shall have the right to make tests to govern the acceptance or rejection in his own test room, or elsewhere, as may be decided by the purchaser, such test, however, to be made at the expense of the purchaser and to be made prior to the shipment of the material. Unless otherwise arranged, any protest based on such tests must be made within 6 days, to be valid. Tests and inspection shall be so conducted as not to interfere unnecessarily with the operation of the mill.

Axle Straightening. A screw press has been successfully used to straighten axles and shafts (see page 306). A wheel press also has been used for this purpose. The bent axle is first mounted between adjustable centers, the distorted section is chalked off and the axle is placed at right angles to the wheel press. The head of the press carries a recessed block to hold the axle in position and a bearing block is placed between the axle and the piston face.

Locating a Crack in Axle. The usual location of a crack in a car axle is near keyway or shoulder. It is almost impossible to find a crack until the axle has been removed from the truck. One method of locating a crack is to wipe the axle clean and allow it to stand for a minute or two. After this a crack may be indicated by black grease oozing from it. A lens will assist in finding this indication. In a doubtful case the axle is sometimes suspended and struck several blows to cause it to vibrate and thus force the grease out of the crack.

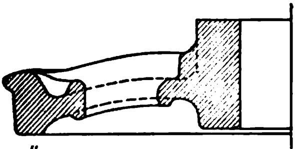
Axle Life. *Factors Other than Crystallization which Determine the Life of an Axle.* The following are replies in the 1908 Question Box, A.E.R.E.A. to the question: What factors determine the limit of life of car axles or when should axles be scrapped?

M. M. Lloyd, East St. Louis & Suburban Ry. Co., East St. Louis: When worn 1/16 in. below original size on motor axle bearings and on journal bearings. *W. M. Roberts, Northern Ohio Traction & Light Co., Akron, Ohio.* When 5/32 in. below original size. *J. H. Adams, Augusta-Aiken Ry. & Light Co., Augusta. Ga.* Small size, worn spots, journals too small, small wheel seats. *C. D. Emmons. Ft. Wayne & Wabash Valley Traction Co., Ft. Wayne. Ind.* Breakage and wear of journals. *D. A. Hegarty, Little Rock Railway & Electric Co., Little Rock, Ark.* The wear of the journal solely.

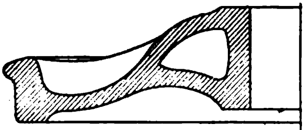
Following are replies in the 1911 Question Box, A.E.R.E.A. to the question: What is the maximum number of miles that a high-speed interurban car axle should make before it is scrapped, as a safeguard against having broken axles?

Wm. Roberts, Northern Ohio Traction & Light Co., Akron, Ohio. 300,000 miles. *C. D. Cass, Waterloo, Cedar Falls & Northern Ry. Co., Waterloo, Iowa.* High-speed interurban axle should never be scrapped as a safeguard against having broken axles, unless it shows a flaw. After an axle has been in service a considerable length of time and it is necessary to turn journals and change wheels, this axle should be annealed. After the annealing process, if a flaw shows up in the axle, it should then be scrapped, and I consider it perfectly safe unless a flaw is discovered. *Geo. M. Knox, Oklahoma Ry. Co., Oklahoma City, Okla.* 500,000 miles. *H. M. Lloyd, British Columbia Elec. Ry., Ltd., Vancouver, B. C.* Would recommend 200,000 miles. Axles should be tested for cracks whenever wheels are changed.

CHART SHOWING TYPES AND WEIGHTS OF 33-IN. CAST-IRON WHEELS RECOMMENDED FOR CITY AND INTERURBAN SERVICE BY THE GRIFFIN WHEEL CO.



33" Curved Arm Channel Spoke Wheel



33" F.C.S. Wheel

Weight of car	City service, 2½-in. tread		Light interurban service, 3-in. tread		Weight of car	Size of axle, A.E.R.E.A. (See p. 428)	Heavy interurban service, 3½-in. tread	Heavy interurban service, M.C.B. Flg. & Trd.
	Spoke	F.C.S.	Spoke	F.C.S.			F.C.S	F.C.S.
32,000	440	......	490	......	55,000	E.B.	640	670
36,000	460	......	510	......	60,000	E.B.	660	690
40,000	480	......	[illegible]	510	65,000	E.B.-1	680	710
44,000	500	480	550	530	70,000	E.B.-1	700	730
48,000	520	500	570	550	75,000	E.C.	720	750
52,000	540	520	590	570	80,000	E.C.	740	770
56,000	560	540	610	590	85,000	E.C.-1	....	790
60,000	580	560	......	610	90,000	E.C.-1	....	810
64,000	600	580	......	630	95,000	E.D.	....	830
68,000	620	600	......	650	100,000	E.D.	....	850

NOTE: Weights of wheels in the above table are for cars operated under normal conditions.

Service[1]	Diam. wheel,	Weight wheel,	Style (See p. 428)	Wheel fit, in.	Size of journal, in.	Capacity, lb.	Rating motor, h	Weight car, lb	b	c	d	e	f	g	h	i	j	k	l	m	n	o	Number bracke
A	31	425	......	4 1/2	....	......	45	36,000 to 44,000	5	4 1/2	1 1/2	4 1/8	4 1/8	3/4	23/32	3/4	1 9/16	1/4	5/8	1 7/32	2 3/8	3 19/32	13
A	33	485	......	4 1/2	....	......	45	36,000 to 44,000	5	4 1/2	1 5/8	4 1/8	4 1/8	3/4	23/32	3/4	1 9/16	1/4	5/8	1 7/32	2 1/2	3 23/32	15
A	33	510	EA	5 7/16	3 3/4 × 7	15,000	45	40,000 to 48,000	5 3/4	5 7/16	7/8	4 5/8	4 5/8	13/16	3/4	13/16	1 9/16	1/4	5/8	1 7/32	2 1/2	3 23/32	15
B	33	535	EB	5 15/16	4 1/4 × 8	19,000	65	46,000 to 56,000	6	5 15/16	5/8	4 5/8	4 5/8	15/16	7/8	15/16	1 9/16	1/4	5/8	1 7/32	2 1/2	3 23/32	15
C	33	560	EB	5 15/16	4 1/4 × 8	19,000	65	44,000 to 54,000	6	5 15/16	1 1/8	4 5/8	4 5/8	15/16	7/8	15/16	1 9/16	1/4	3/4	1 9/32	3	4 9/32	15
D	33	640	EB-1	5 15/16	4 1/4 × 8	22,000	100	50,000 to 60,000	6 7/16	5 15/16	1 3/16	4 5/8	4 5/8	1 1/16	1	1 1/16	1 5/8	1/4	7/8	1 7/16	3 1/2	4 15/16	15
E	33	730	EC	6 15/16	5 × 9	27,000	150	60,000 to 70,000	6 3/8	6 15/16	7/8	5 1/16	4 7/8	1 1/8	1 1/16	1 1/8	1 5/8	1/4	1	1 1/2	4 1/8	5 5/8	15
E	33	800	EC-1	6 15/16	5 × 9	31,000	200	70,000 to 80,000	6 3/8	6 15/16	7/8	5 1/16	4 7/8	1 1/4	1 3/16	1 1/4	1 3/4	1/4	1	1 1/2	4 1/8	5 5/8	15
E	33	850	ED	7 15/16	5 1/2 × 10	38,000	250	80,000 to 100,000	6 3/8	7 15/16	7/8	5 9/16	5 3/8	1 3/8	1 5/16	1 3/8	1 7/8	1/4	1	1 1/2	4 1/8	5 5/8	15
E	36	800	EB-1	5 15/16	4 1/4 × 8	22,000	100	60,000 to 70,000	6 3/4	5 15/16	7/8	4 3/4	4 3/4	1	1	1 1/8	1 7/8	1/4	7/8	1 7/16	3 1/2	4 15/16	18
E	36	925	EC-1	6 15/16	5 × 9	31,000	200	80,000 to 90,000	7	7	7/8	5 1/4	5 1/8	1 3/8	1 3/16	1 1/4	....	....	1	....	4 1/8	......	16

[1] A = City .B = Heavy City. C = Light interurban. D = Ordinary interurban. E = High speed interurban.

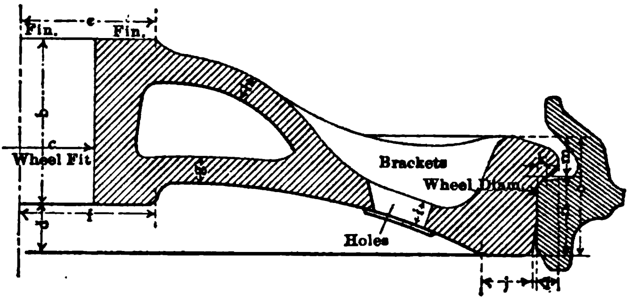


FIG. 21.—Griffin Wheel Co. F.C.S. cast-iron wheel.

Effect of Dimensions on Weight of Cast-iron Wheel. Considering cast-iron wheels of the same general design, a 36-in. wheel will weigh approximately 100 lb. more than a 33-in. wheel, and a 30-in. wheel will weigh approximately 75 lb. less than a 33-in. wheel. Increasing the width of tread affects the weight of wheel approximately as follows:

Diameter of wheel, in.	Increase in weight of wheel per inch increase in width of tread, lb.
36	60
33	50
30	40
24	32
20	24

Wheel Grinding. Chilled cast-iron wheels which would have been removed from service because of worn flat spots, slight chipping, worn tread, or sharp flange have been made to give from 25 to 40 per cent. more service by grinding. By close attention to the grinding out of flat spots track and truck maintenance costs have been reduced in addition to securing the increased mileage. Whether the wheel is worn out or another grinding will be economical may be decided from a comparison of the worn diameter or circumference with the original depth of the chill. A high abrasive such as emery or alundum in the form of a block or wheel has been used for the grinding. The best practice is to grind both mating car wheels, thus maintaining the same diameter for both. A method of grinding out flat spots employed on many roads is to use a brake-shoe of abrasive material until the flat spot is ground out. This method calls for close watching in order that the grinding shoe may be removed as soon as the flat spot is eliminated. A method which has been used with success is to jack up the end of the car which carries the flat wheel and spin that wheel against a block of the abrasive while the other pair of wheels is blocked. The use of the abrasive in the form of a grinding wheel in a grinding machine is most satisfactory. A separate grinding wheel is used for each of the mating car wheels. The car wheels and grinding wheels are revolved in opposite directions and the dust is conducted away by a blower. The car wheels are revolved at 10 to

15 r.p.m. The grinding wheels are from 14 to 18 in. in diameter by from 2 to 2½ in. in thickness and have a peripheral speed of about 5000 ft. per minute. In some machines the feed is automatic. The power required depends upon the rapidity of grinding, but for ordinary work it amounts to about 10 h.p. There are two general types of grinding machine; the floor grinder and the pit grinder. In using the floor grinder the axle carrying the pair of wheels to be ground is removed from the truck and mounted in bearings in the grinder, a sprocket wheel is fastened to the axle and it is revolved by a chain driven by the motor which drives the wheels. In the pit grinder the end of the car carrying the flat wheel is raised, a short piece of rail is removed from beneath each of the wheels to be ground, the grinding wheels are adjusted to the wheel treads in place of the rails removed and the car motor driving the pair of wheels being ground is run with the controller on the first notch and a water rheostat is used in place of the regular grid resistor. If trailer wheels are to be ground a sprocket wheel is attached to their axle and is driven by the grinder motor. The removal of ordinary flat spots requires from 10 to 40 minutes actual grinding.

It has been found advantageous to grind chilled cast-iron wheels after mounting them and before putting them into service. Such grinding will correct for possible defects and thus aid in securing the most satisfactory wheel service. Wheels may thus be brought to the same diameter, wheels out of round, or warped, may be trued, and in case the axle has not been turned perfectly, the wheels bored not in the center, or the wheel improperly pressed onto the axle, grinding the wheel will make the wheel tread, flange and journal coaxial.

Solid Wrought Carbon-Steel Wheels for Electric Railway Service (A.E.R.E.A. Standard Specification)

Process: 1. Steel for wheels shall be made by the open-hearth process.

Discard: 2. A sufficient discard shall be made from each ingot to secure freedom from injurious pipes and undue segregation.

Chemical Composition: 3. The steel shall conform to the following limits in chemical composition:

	Acid steel	Basic steel
Carbon	0.60 to 0.80 per cent.	0.65 to 0.85 per cent.
Manganese	0.60 to 0.80 per cent.	0.60 to 0.80 per cent.
Silicon	0.15 to 0.35 per cent.	0.10 to 0.30 per cent.
Phosphorus, not over	0.05 per cent.	0.05 per cent.
Sulphur, not over	0.05 per cent.	0.05 per cent.

Sample for Chemical Analysis (Ladle Analysis): 4. To determine whether the material conforms to the requirements specified in Section 3, an analysis shall be made by the manufacturer from a test ingot taken during the pouring of each melt. A copy of these analyses, together with the necessary identifying records, shall be furnished to the purchaser or his representative.

Check Analysis: 5. A check analysis may be made by the purchaser of drillings obtained by drilling through the plate of one wheel, selected at random from each heat, two holes of suitable size, ninety (90) degrees apart, and so located as not to impair the usefulness of the wheel, drilling for analysis being by boring entirely through the plate of the wheel parallel to the axis of the wheel. Drillings shall be clean and free from scale or other foreign substances, and may be analyzed either separately or mixed, at the discretion of the engineer. Analyses from these drillings shall conform to the requirements specified in Section 3 and shall not vary more than ten (10) points in carbon from the heat analysis, and when analyzed separately shall not vary more than ten (10) points in carbon from each other, except that, if analyses of drillings vary more than ten (10) points in carbon from the heat analysis but still fall within the limits specified in Section 3, then drillings from two additional wheels from the heat so varying may be taken and the average of the analyses from the three wheels substituted for the analysis from the test ingot, as the heat analysis.

Finish: 6. All wheels shall be free from injurious seams, cracks, laminations or other defects detrimental to strength or service. Wheels for inspection must not be painted or covered with any substance to in any way hide defects, nor rusted to such an extent as to hide defects.

Workmanship: 7. Wheels are to be furnished with rim contours machined and to the tolerances designated as (*b*) except that when service conditions permit and when agreed to by the purchaser, rim contours may be either unmachined or machined and shall conform to tolerances (*a*). All dimensions shall conform to the dimensions of Drawing No. —, which is made a part hereof, subject to the tolerances designated. (See Fig. 22.)

Height of Flange: 7(*a*) The height of the flange shall not vary from the dimension specified more than (*a*) 1/16 in. or (*b*) 1/32 in.

Thickness of Flange: 7(*b*) The thickness of flange shall not vary from the dimension specified more than (*a*) 1/16 in. or (*b*) 1/32 in.

Radius of Throat: 7(*c*) The radius of throat shall not vary from the dimension specified more than (*a*) 1/16 in. or (*b*) 1/32 in.

Thickness of Rim: 7(*d*) The thickness of rim shall not vary from the dimension specified more than 1/4 in. over or 1/8 in. under.

Width of Rim: 7(*e*) The width of rim shall not vary from the dimension specified more than (*a*) 1/8 in. or (*b*) 1/16 in.

Thickness of Plate: 7(*f*) The thickness of plate shall not vary from the dimension specified more than 1/32 in. per 1/8 in. thickness of plate.

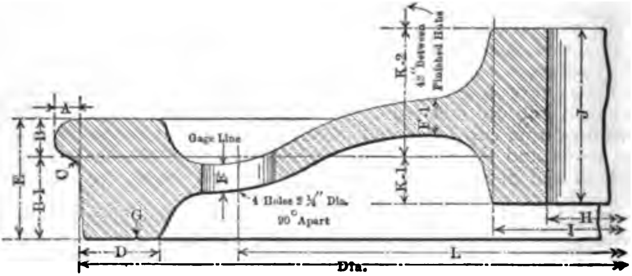
Limit Groove: 7(*g*) When limit groove is specified, the location of the center of limit-of-wear groove shall not vary from the dimension specified more than 1/16 in.

Diameter of Bore: 7(*h*) The diameter of bore shall not vary from that specified more than 1/16 in. over or 1/8 in. under. When not specified, the diameter of rough bore shall be 1/4 in. less than the diameter of finished bore, subject to the above limitations.

Diameter of Hub: 7(*i*) The diameter of hub shall not be less, but may be 3/4 in. more than that specified, but the thickness of wall of the finished bored hub shall not be less than 1 in. at any point for bores up to 6 in. in diameter, and not less than 1¼ in. for bores over 6 in. in diameter unless otherwise specified.

Eccentricity of Hub: 7(*ii*) The thickness of hub wall shall not vary more than ⅜ in. between any two points in the diameter of the hub.

Length of Hub: 7(*j*) The length of hub shall not vary from the dimension specified more than ³⁄₁₆ in.



Ref. Letter	Dimension		Specified Tolerances		Ref. Letter	Dimension		Specified Tolerances	
			Over	Under				Over	Under
Dia.			Tape	Size	F			⅛"	⅛"
			6	4	F-1			⅛"	⅛"
A		Machined	1/32"	1/32"	G			1/16"	1/16"
		Unmachined	1/16"	1/16"	H			1/16"	⅛"
B		Machined	1/32"	1/32"	I			⅛"	0"
		Unmachined	1/16"	1/16"	J			5/32"	5/32"
B-1		Machined			K-1			⅛"	⅛"
		Unmachined			K-2			1/32"	1/32"
C		Machined	1/32"	1/32"	L				
		Unmachined	1/16"	1/16"					
D		Machined	¼"	⅛"					
		Unmachined	¼"	⅛"					
E		Machined	1/16"	1/16"					
		Unmachined	⅛"	⅛"					

FIG. 22.—A.E.R.E.A. solid steel wheel.

Projection of Front Face of Hub: 7(*k*) The projection of front face of hub shall not vary from the dimension specified more than ⅛ in.

Projection of Back Face of Hub: 7(*kk*) The projection of back face of hub shall not vary from the dimension specified more than 1/32 in.

Black Spots on Hub: 7(*l*) Black spots deeper than 1/16 in. will not be permitted in rough bore within two (2) inches of either face of hub.

Eccentricity of Bore: 7(*m*) The eccentricity of bore between the center line of tread and center line of rough bore shall not exceed 3/64 in.

Block Marks on Tread: 7(*n*) Block marks shall not exceed 1/64 in. in height.

Rotundity: 7(*o*) Wheels, except those with full machined contour shall be gaged with a ring gage and the opening between the gage and tread, at any point, shall not exceed $\frac{1}{16}$ in.

Plane: 7(*p*) Wheels shall be gaged with a ring gage concentric with and perpendicular to the axis of the wheel. All points on the gage line equidistant from the center and the center line of throat and flange at all points must bear the same relation to the plane ring gage as the back of the flange does to the ring. These measurements shall not vary from those specified more than (*a*) $\frac{1}{16}$ in. or (*b*) $\frac{1}{32}$ in.

Tape Sizes: 7(*q*) Wheels shall not vary from the tape sizes specified more than four (4) tapes under or six (6) tapes over except that wheels with treads wider than three (3) inches may vary five (5) tapes under or nine (9) over.

Mating: 7(*r*) All wheels shall be measured by standard tape and the tape numbers clearly marked on the web of the wheel. Wheels shall be shipped in pairs mated by tape numbers and, so far as possible, also by heat numbers. Wheels having machined contours shall not be mated with wheels having unmachined contours.

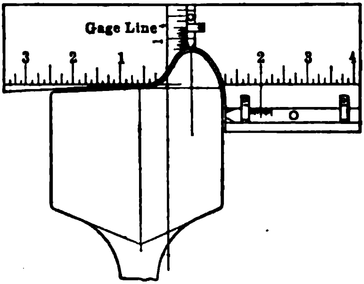


Fig. 23.—Tolerance gage for steel wheels.

Gages and Tapes: 8. The manufacturer shall provide suitable gages and tapes which shall conform to the contour and dimensions of the wheels shown in Drawing No. ——, and approved by the purchaser. (For tolerance gage see Fig. 23.)

Branding: 9. Wheels shall be stamped with the manufacturer's mark, heat number and serial number of the wheels, while hot, in such manner that each wheel may at any time be readily identified. The wheel shall be so marked as to indicate its location in the ingot when more than one wheel is made from an ingot. (See Fig. 24.)

Inspection: 10(*a*). The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the wheels ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the wheels are being furnished in accordance with this specification. Tests and inspection shall be made prior to shipment unless otherwise arranged.

10(*b*). The purchaser may make the tests to govern the acceptance or rejection of material in his own laboratory or elsewhere. Such tests, however, shall be made at the expense of the purchaser.

10(*c*). All tests and inspection shall be so conducted as not to interfere unnecessarily with the operation of the works.

10(*d*). Wheels, which show injurious defects while being finish-by the purchaser, will be rejected, and returned to the manufacturer, who shall pay return freight.

10(*e*). Unless otherwise arranged, any rejection based on tests made in accordance with section 10(*b*) shall be reported within 10 working days from the receipt of samples.

10(*f*). Samples tested in accordance with section 10(*b*), which represent rejected material, shall be preserved for 2 weeks from the date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a re-consideration within that time.

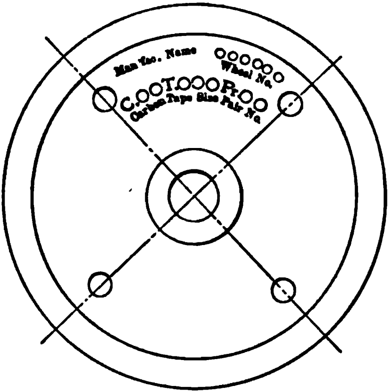


Fig. 24.—A.E.R.E.A. standard marking for steel wheels.

10(*g*). The manufacturer shall replace, free of charge, any wheels sold, delivered and manufactured under this specification that may at any time prove defective in either material or workmanship.

Rolled Steel Wheels. The general replies from fifty operating companies to questions regarding solid steel wheels sent out by the 1909 Committee on Equipment, A.E.R.E.A., were as follows: The diameters when new range from 30 to 37¼ in. New rims are from 2 to 3¾ in. thick. These are worn down by some companies to as low as ½ in. Others wear down to 1¼ in., while the average considers ¾ in. to be safe. The average number of turnings is three. Solid rolled steel wheels are considered safer than steel-tired wheels for interurban service. They are also held to be more economical, scrap considered. The diameter of hub face which bears against the collar of axle liner considered most desirable was as follows: 9 in. for motor of not over 45 h.p.; 10 in. for motor of over 45 h.p. and less than 100 h.p.; 10½ in. for motor of over 100 h.p.

Mileage between Turnings of Steel Wheel. Following are replies in the 1909 Question Box, A.E.R.E.A. to the question: In using steel wheels, what mileage should be had between turnings, what wear from service, and how much turned off?

L. E. Sinclair, Washington (D. C.) Railway and Electric Co. About 25,000 miles between turnings, approximately ⅛ in. in diameter of wear, and we turn down from ¾ in. to 1 in. in diameter. *L. W. Jacques, Fort Wayne (Ind.) & Wabash Valley Traction Co.* About 45,000 and as little to be turned off as possible to obtain the contour of the flange.

The average pair of solid rolled steel wheels in the New York Subway runs 15,000 to 20,000 miles before requiring turning, and each pair has a life of about five turnings. The average reduction in diameter is ⅜ in. per turning.

From tests on the Brooklyn Rapid Transit System, 1911, it was concluded that a steel wheel on a surface car will run about 8000 miles per 1/16 in. radial wear.

Wheel Turning. New York Subway wheels are turned in two Pond center-drive lathes. Of these one is driven by a 20-h.p. motor and the other, which is one of a newer and heavier type of construction, by a 40-h.p. motor. The latter is equipped with air-operated tail stocks and both have the cutting tools clamped in the tool post by means of compressed air. The output of the former lathe is twelve pairs of wheels per day, while the latter machine has a capacity of twenty pairs per day. Payment of the operators of these machines is made by the inch of finished diameter of wheels. The small lathe pays 1 cent per inch of finished diameter, but on account of its great capacity and its labor-saving devices the large lathe pays but ½ cent per inch. The great stiffness and pulling power of the latter machine permits the finished cut on the wheels to be taken with a forming tool which gives proper contour with one cut.

The necessity for turning is most often determined by flange wear. It may also be determined by flat spots on the tread or by the allowable difference between the circumferences of two wheels rigidly fastened to the same axle or geared or linked together. This allowable difference is often taken to be ⅛ in. in ordinary electric railway work and a consideration of it is of greater importance on driving wheels than on trailers.

Turning Steel Wheels having Thick and Thin Flanges. Following is the process of the Twin Cities Rapid Transit Co., Minneapolis, in correcting wheels removed for re-turning which have one thick and one thin flange per mated pair of wheels. Each pair of wheels is taped and sufficient metal is turned from both the flange and tread of the larger wheel, which as a rule is the one with the thick flange, to mate it roughly with the wheel of smaller diameter. At times it is necessary also to turn slightly the outside of the tread of the thin-flanged wheel to true it. Then a groove ¼ in. wide by ⅛ in. deep is turned in the tread of the thin-flanged wheel, at the point where the throat of the renewed flange should begin to form. After the treads of both wheels have been rough-mated in the foregoing manner, they are set in the wheel grinder where the treads are brought accurately to the same diameter. This grinding process is continued until the treads are perfectly polished and true, except at the groove in the thin-flanged wheel, which may or may not be removed, depending on the depth of grinding necessary to true the wheels. The size and the location of the groove serves only as a guide to the workman doing the grinding as it defines the tread width. The existence of the groove also makes it easy for a workman to bring the grinding tool close up to the proper place for the root of the flange, with the result that the tread is ground true. In consequence, wheels readily adjust themselves to the right position on the track, and at least the immediate tendency to continue the cutting of the flanges after they have been restored in service has been eliminated. Although the depth of the groove in the tread is ⅛ in. after the wheel has been turned, the grinding process practically removes all evidence of it from most wheels. That portion of the groove remaining on some wheels after the grinding process has been found not to affect the wear in any way. This is probably due to the fact that it is turned at a point on the tread—namely, the throat of the flange—which under ordinary conditions does not come in contact with the rail or, at least, does not come in contact with it until the wheel has been in service for some time. At first there was considerable apprehension as to the effect of the grooves in operation. Records show, however, that they have not been responsible for derailments, either at switches or curves. When wheels treated by this process are replaced in the truck they are reversed from their original position and made trailing wheels if they were leading, or *vice versa*. No efforts, however, are made to replace the wheels under the car from which they were removed. This makes it possible to conform to the rule of reversing the wheels at all times, but as a general rule, if a pair of wheels is brought into the shop as No. 1 wheels, they are replaced in service as No. 2 wheels. In some instances, the trucks are turned and placed at the opposite end of the car from which they were removed. This interchange of trucks restores the wheels to the same position under the car as they were before removal for turning. Wheel removals for thin flanges after receiving the foregoing treatment are rare.

Mounting Wheels. The following specifications were submitted for consideration at the 1910 Convention of the Master Car Builders' Association: Axle wheel fit must be turned as smooth as possible with lathe tool having flat cutting edge. Finishing cut must not be taken with lathe feed coarser than 16 pitch. Taper on axle wheel seat for entering wheel must not exceed ½ in. in length and must be turned with broad, straight-faced tool, making regular taper without ridges or rings. Wheel fits to be calipered at three points, namely: 1 in. from each end and middle, and other points if indications point to excessive variations in diameter. Axles shall not be considered as suitable for mounting where there is a difference in diameter between any two measurements exceeding 0.003 in. This, however, shall not be construed to mean that wheel seats from each end of axle are to be of one size. Each tenth axle from each lathe shall be measured for soundness. No axle varying over 0.001 in. when measured at two points 90 deg. apart on circumference at equal distance from end shall be considered as suitable for mounting.

Wheels to be bored smooth. Finishing cut shall be made with tool or tools having a cutting face at least 3/16 in. wide. Feed not to exceed 8 pitch. To be bored with a rough and finishing cut. The finishing cutter when taking the finishing cut must not be cutting when roughing tool is also rough boring, unless the finishing tool is supported independent of roughing tool, the latter to prevent spring of roughing tool being transmitted to finish tool, causing an irregular bore.

Wheels to be calipered with micrometer caliper. A wheel varying over 0.002 in. in any two diameters will not be considered satisfactory for mounting.

Mounting presses to be provided with recording pressure gages. All wheels not mounted within limits given, or wheels that are forced against shoulder, to be withdrawn.

It would be very desirable if all shops were to adopt one angle for lathe centers. Generally, lathe centers used for ordinary work are 60 deg., including angle. If this were adopted for all axle work, it would result in the axles running true on centers, reducing the amount of material necessary to turn away when truing up axles that have been previously turned.

Mounting Pressure. The committee which submitted the above specifications recommended the following mounting pressures:

M.C.B. axle (see p. 429)	Size of journal	Wheels			
		Cast iron, tons		Steel, tons	
		Maximum	Minimum	Maximum	Minimum
A	3¾ in. by 7 in.	44	36	66	54
B	4¼ in. by 8 in.	44	36	66	54
C	5 in. by 9 in.	55	45	83	68
D	5½ in. by 10 in.	55	45	83	68

The workmanship in boring the wheel and turning the wheel seat of the axle should be specified when specifying the mounting pressure.

In New York Subway Service wheel seats on axles receive a dead smooth finish. After the finishing cut in the axle lathe they are run over lightly with a file. Wheels are bored with an expansion boring bar to required sizes and pressed on over a coat of white lead on the wheel seat. Motor wheels are pressed on at pressures between the limits of 60 tons and 90 tons. Pressures between 50 tons and 75 tons are used for trailer wheels. Motor wheel hubs on both sides of the wheel are banded with steel rings 2¼ in. high and 1½ in. thick, the hub diameter at the point of banding being 10 in. The hub rings are added to give additional security against loose wheels and their installation has absolutely stopped this common trouble. They are shrunk on at gas-flame temperature with a shrinkage of 0.001 in. per inch of hub diameter. The rings are applied after pressing the wheel on the axle.

Removing Wheel from Axle. The pressure ordinarily required to remove a wheel from its axle will vary from two to five times that at which the wheel was mounted. The wheel press is often used to apply this pressure whose amount generally lies between 150 tons and 300 tons. Heating the wheel and hammering while the pressure is applied are often resorted to in starting the wheel. A drop hammer has also been used alone to start the wheel which was afterward removed by the wheel press.

Shrink Fits. The process of shrinking wheels and gears to axles and tires to wheels is outlined in the following citation of the practice on the New York, Westchester and Boston Railway by Mr. R. R. Potter: The parts are bored accurately to a certain diameter in relation to the axle, micrometers being used in measuring. The part is then heated and placed on the axle without pressure. By this method there is no abrasion on the finished surfaces of the axle, wheel or gear due to the process of application. Also, as heat is applied to the part when it is removed, very little abrasion occurs, due to the process of removal. In addition, the parts may be replaced in their original positions a number of times, without loss of holding power. The axles, at the location of wheel seats, are carefully finished and filed as smooth as possible. Wheels and gears as well as tires are bored 0.001 in. smaller than the axle or wheel center per inch of diameter of bore, and then they are heated and slipped into place. After the wheels have been applied and have cooled, they are tested in the wheel press at a pressure of 10 tons per inch diameter of bore. The gears are heated at center with a torch using compressed air and city gas, but the rims are not allowed to go above 300 deg. F., as measured with a thermometer set with the bulb in a special cup which fits between the gear teeth. It is found that this temperature invariably gives sufficient expansion to permit gears to be slipped on without any pressure. Wheels are heated with the same torch until a drop of water at the middle of the spoke will boil freely when dropped onto it. Wheels sometimes require a slight pressure in addition to the heating to move them into place, but this is negligible in comparison with those used in ordinary press fits. When wheels or gears are thus shrunk onto the axles, the microscopic points of metal are not smoothed down as they are when a wheel is pushed on cold, and the result is that these points interlock and make a very close and secure fit.

Holding Power of Steel Tire. In the New York Subway where wheels are heated excessively due to frequent great acceleration and heavy braking, the highest temperature of the tire of a wheel just taken from service was found to be 145.4 deg. F., and the corresponding temperature of the hub was 87.8 deg. F. After this was investigated, the holding power of steel tires shrunk on with the standard shrinkage allowance of 0.001 in. per 1 in. diameter was calculated. The results are shown by the following table:

Shrinkage allowance	Temp. of tire	Temp. of hub	Radial pressure of tire on wheel center	
			Tire 2⅝ in. thick	Tire 1⅛ in. thick
0.03 in.	60° F.	60° F.	6070 lb. per sq. in.	2600 lb. per sq. in.
0.03 in.	145° F.	88° F.	3970 lb. per sq. in.	1700 lb. per sq. in.

Percentage reduction in holding power caused by wear, 57 per cent.
Percentage reduction in holding power caused by heat, 35 per cent.
Percentage reduction in holding power caused by wear and heat, 92 per cent.

Life of Wheel: Solid Steel, Steel Tired and Cast Iron. Following are replies in the 1909 Question Box, A.E.R.E.A., to the question: What is considered good mileage for solid steel wheels, steel tired wheels and cast-iron wheels, allowing three turnings for steel?

L. E. Sinclair, Washington (D. C.) Ry. & Electric Co. For steel and steel tired wheels, an average of about 90,000 miles; cast-iron wheels, about 40,000 miles. *L. W. Jacques, Ft. Wayne (Ind.) & Wabash Valley Trac. Co.:* 250,000 miles, 220,000 miles and 45,000 miles, respectively. *W. R. McRae, Toronto Ry. Co.* Cast-iron wheels should average from 35,000 to 45,000 miles. *Wm. A. House, The United Rys. & Electric Co. of Baltimore.* Steel wheels should give at least 150,000 miles, and cast-iron wheels should give at least 30,000 miles. *D. A. Hegarty, Little Rock (Ark.) Ry. & Electric Co.* Cast-iron wheels we used gave us an average of 58,000 miles in 1908. *Dudley Montgomery, Southern Wisconsin Ry. Co.:* 40,000 miles for cast-iron wheels on 12-ton car. *M. M. Lloyd, East St. Louis (Ill.) & Suburban Ry. Co.* Depending upon service conditions, cast-iron wheels should average 40,000 miles.

The rim of a new solid steel wheel on the New York Subway is 3¾ in. thick and when this is turned down to 1¼ in., the wheel is scrapped.

The life of chilled cast-steel wheels used by the Columbus Railway and Light Co. is 73,157 miles for 18-in. and 20-in. pony wheels and 61,563 miles for 33-in. wheels.

At the 1911 Convention of the Iowa Street and Interurban Association Mr. C. M. Feist of the Sioux City Service Company called attention to the high mileages obtained as a result of careful attention and the use of a wheel grinder. The average life of cast-iron wheels on the Sioux City property as determined for a period of 6 years was 97,000 miles for 30-in. wheels and 137,000 miles for 33-in. wheels. The wheels had about a ⅞-in. chill and were worn down about 1 in. in diameter before scrapping. All wheels were ground before being put into service.

See also page 466 on flange lubrication.

Wheel Defects. The following relative to common wheel defects is from a talk by F. A. Beebe of the Griffin Wheel Co. at the Hartford Shops of the Connecticut Co., 1910:

Thin Flange. A thin flange may be due to one or more of the following causes: (*a*) Wheels improperly mated as to diameters. (*b*) Improperly mounted as to gage. (*c*) Improperly put on axles; that is, the distance from end of journal to gage-line on one end of axle being greater than the other. (*d*) Improperly shaped flange. (*e*) Trucks out of true. (*f*) Car riding on side bearings, preventing free movement of the truck, bringing the work of turning on the flange. (*g*) Track out of gage on curves. (*h*) Improper elevation of outer rail. (*i*) Running car in one direction; that is, when car at the end of the line runs around a loop instead of being turned. (*i*) Sanding one rail, causing one wheel to wear down faster than its mate.

Warped Flange. A cast-iron wheel flange warpage of about $\frac{3}{16}$ in. is allowable.

Elimination of Flat Spots. (*a*) See that the brake-shoes are properly adjusted. (*b*) Braking apparatus adjusted so that in coming to a stop the wheel will not lock. (*c*) See that the percentage of brake pressure is in proper relation to the load on the wheels. (*d*) An important point is the manner of hanging the brake. Most brake hangers are placed below a line passing through the center of the axle, parallel with the trucks, which allows the brake to fall away from the wheel by gravity. This angle may be made too large, so that with badly worn and loose parts the application of the brakes causes the shoe to crowd up against the wheel. This makes a toggle joint, producing excessive pressure on one pair of wheels in the truck causing them to stop rolling while the other pair is still revolving. This is a prolific cause of slid flats and also results in excessive wheel wear.

Wheel Gage. Figs. 25 and 26 show the wheel gage used on the Bay State Street Railway, Mass. The wheels are mounted from the gage-line and equidistant from a punch mark at the center of the axle. The gage is made of seasoned ash with No. 14 steel plate on one side and a ¼ in. thick steel plate on the other. The latter plate is machined out to rest only on the tread and contour of the wheel at the gage-line and against the back of flange, allowing merely enough clearance to take care of the tolerance variation of the wheel. The pointer placed at the center has a ⅜ by ¼-in. thumb screw at its lower support to make adjustments for differences in the diameter of the wheels.

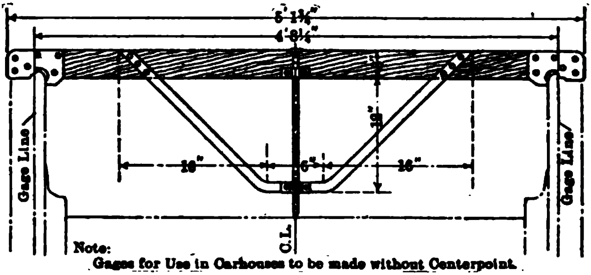


FIG. 25.—Wheel gage, Bay State St. Ry.

Wheel Wear Inspection. Details of the wheel defect gage used by the Public Service Railway Co., Newark, are given in Fig. 27. The application of this gage in testing wheels is shown by Figs. 28 to 33, inclusive. Following are the rules according to which wheels tested are disposed of:

Flange. 1. Flanges whose height is greater than ⅞ in. shall be turned or ground down or rejected, excepting in case of wheels with ⅞-in. normal flange, in which case the maximum height shall be 1 in. 2. Wheels having flanges less than ⅝ in. height shall be turned or ground down or rejected, except for ⅞-in. normal flanges which have a height of ¹¹⁄₁₆ in. minimum. 3. Flanges greater than 1¼ in. in thickness shall be turned or ground down or rejected. 4. Wheels showing a "double" flange shall be turned or ground down or rejected. 5. Cast wheels having flanges less than ¾-in. in thickness measured at the gage-line shall be rejected. Steel wheels measuring less than ⅝ in. shall be rejected. 6. Flanges having flat vertical surfaces extending more than ½ in. from tread shall be turned or ground to a rounded contour or be rejected. 7. All flanges showing small chips extending for more than 30 per cent. of the circumference of the flanges shall be turned or ground down or rejected; but no chips on the outside of the flange greater than 3/16 in. deep, 1½ in. long, ½ in. wide, or that extend ⅛ in. past the center will be allowed, and no chips on the inside of the flange greater than ⅛ in. deep, 1 in. long, ½ in. wide or that extend ⅛ in. past the center of the flange or that are less than ¼ in. from the tread will be allowed.

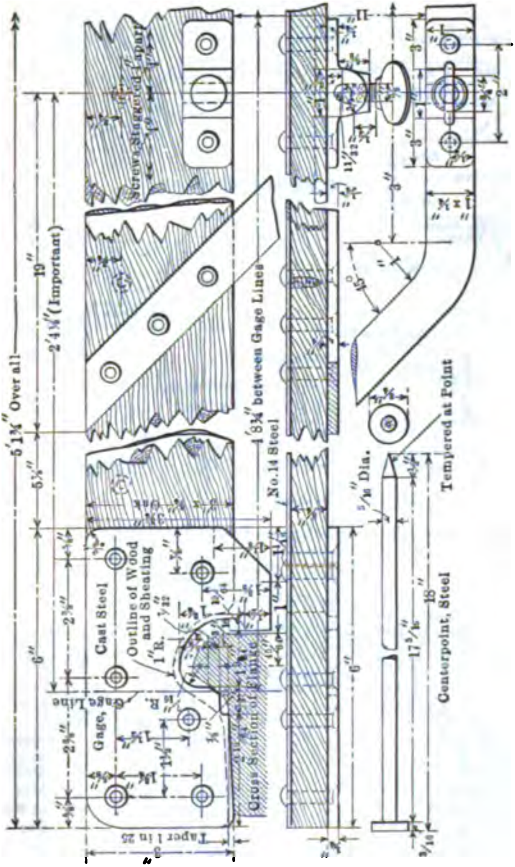


FIG. 26.—Details of wheel gage, Bay State St. Ry.

Tread. 8. Wheels having treads less than 2 in. in width shall be rejected, excepting in case of wheels with 3-in. normal tread, in which case the minimum tread shall be 2¼ in. 9. All wheels having "shelled-out" spots in tread exceeding 2 in. by ½ in., or less than ½ in. from flange shall be turned or ground down or rejected. 10. Wheels showing seams more than 1 in. long at a distance of ½ in. or less from the throat of the flange, or seams more than 3 in. long on any other part of the tread shall be rejected. 11. Cast wheel showing "soft" spots (worn through the chill) on tread exceeding 2 in. in length shall be rejected. 12. Wheels showing "flat" spots on tread shall be turned or ground down or rejected.

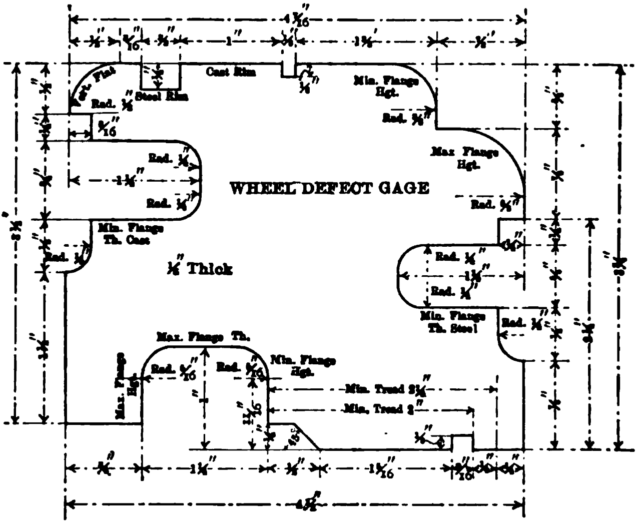
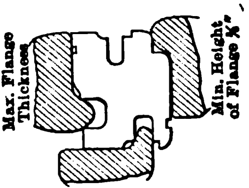
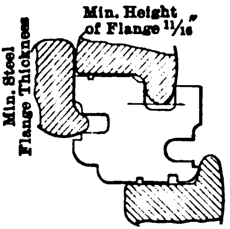


FIG. 27.—Wheel defect gage, Public Service Ry., N. J.



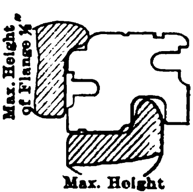
Min. Cast Iron Flange Thickness

FIG. 28.



Max. Vertical Flat

FIG. 29.



Max. Height of Flange 1"

FIG. 30.

Applications of wheel defect gage, Public Service.

Rim. 13. Cast wheels that are worn through the chill or whose rim is less than 1 in. thick shall be rejected. Steel wheels whose rim is less than ¾ in. thick shall be rejected.

Gage. 14. The distance back to back of flanges shall not be less than 4 ft. 5 13/16 in., Southern Division 4 ft. 9 5/16 in. 15. Wheels more than 1/8 in. over or 1/2 in. under gage shall be reset.

Details of the wheel defect gage used by the New York Subway

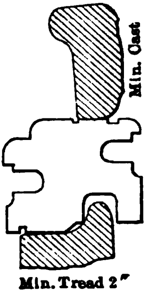


FIG. 31.

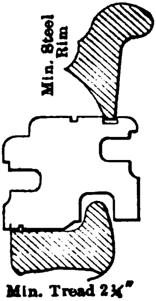


FIG. 32.

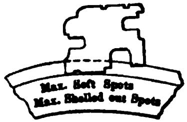


FIG. 33.

Applications of wheel defect gage, Public Service.

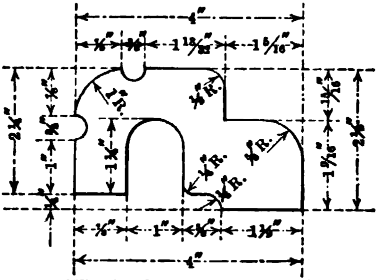


FIG. 34.—Wheel defect gage, New York Subway.

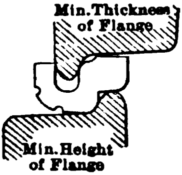


FIG. 35.

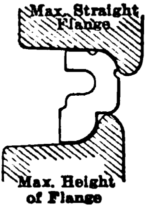


FIG. 36.

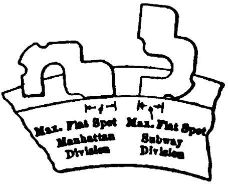

Max. Flat Spot Manhattan Division
Max. Flat Spot Subway Division

FIG. 37.

Applications of wheel defect gage, New York Subway.

are given by Fig. 34. The application of this gage is shown by Figs. 35, 36 and 37. In the contour tests the straight portion of the gage lying nearest the wheel tread should in all cases be kept horizontal—that is, when the wheel axle is horizontal.

A.E.R.E.A. Standard Section of Tread and Flange of Wheel. For street and interurban railways, as far as can be applied, a wheel tread and flange contour, which conforms to that shown in Fig. 38 and indicated as Wheel *A* has been approved as a standard of the Association. This wheel has a tread 3 in. wide, a flange ⅞ in. high and the thickness at the throat is 1¹⁄₁₆ in. Wheel *A* is further recommended for use in interurban work with the tread increased to 3½ in., and also for city work where it can be used, as this wide tread assists in carrying the load across special work without running on the flange and avoids the necessity for flange bearing on the special work. To meet local conditions where it is impossible to operate with Wheel *A*, Wheel *B* is standard. It has a tread of 2½ in. and a flange ¾ in. high. This flange has the same general dimensions as Wheel *A* with the exception of the height above the tread line. In mounting and gaging wheels it is understood that the gage-line is at a point on the flange ¼ in. above the wheel tread and wheels should be gaged ¼ in. narrower than the gage of the track, the track gage being measured between points ¼ in. below the tops of the rails.

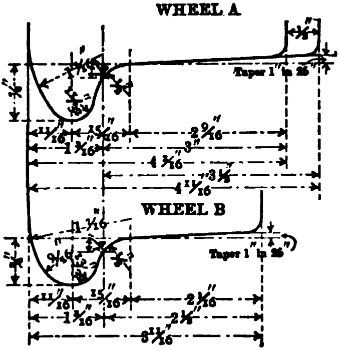


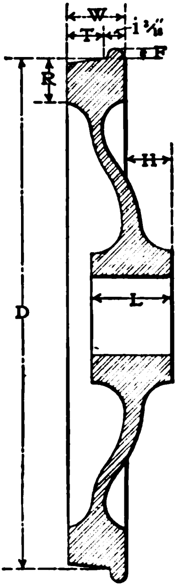
FIG. 38.—A.E.R.E.A. standard wheel treads and flanges.

Dimensions of Rolled Steel Wheels (A.E.R.E.A. Recommended Design). (Fig. 39.)

Advantages of Large Wheel. Following are some of the advantages of the large wheel: It affords greater mileage between turnings, gives lower journal surface speed with consequently comparatively little wear and axle steel fatiguing stresses per car mile, causes smaller stresses to be set up in wheel and rail surfaces, strikes lighter blows on the track and is less liable to give trouble at a defective frog, switch-point or rail. A large wheel makes possible the use of a large gear and maximum gear reduction with a corresponding high motor speed which permits the use of a comparatively small light-weight motor and necessitates the least energy consumption. Special installations may be such that the above advantages would be inferior to the advantages accompanying the use of very small wheels. Thus, the satisfactory design of many low floor cars has demanded wheels of small diameter.

Determination of Truck Wheel Base. In a paper before the Central Electric Railway Association, 1908, A. C. Vauclain of the Baldwin Locomotive Works stated that the final determination of the wheel base should, if curves permit, be based entirely upon the transom width being sufficient to allow a proper width of bolster and bolster springs, and the fixed length of the motors measured from their axle journals to their supporting noses.

Wheel Base for City Service. The following are replies in the Question Box, Aera, 1912, to the question: "Is a 4- or 6-ft. wheel base truck best for purely city service where short radii curves are used?" *L. M. Clark, Indianapolis Traction and Terminal Co.* We consider inside-hung motor trucks of an approximate 6-ft. 0-in. wheel base superior to outside-hung motor trucks of short wheel base for the following reasons: First, the lesser displacement of tractive effort between the two pairs of wheels during acceleration and running, more particularly the former; second, greater factor of strength on account of the location of motor suspension in close proximity to the center of truck; third, less wheel flange pressures against rail heads required to swivel trucks on curves, and also occurring during "nosing" periods; fourth, easier riding qualities. *John Lindall, Boston Elevated Railway Co.* In my judgment a 6-ft. wheel base truck is preferable on account of less liability to derail; less flange wear; and less tendency to cause rail corrugations. *Geo. W. Knox, Oklahoma Railway Co.* The use of 4-ft. wheel base trucks for purely city service is desirable only by reason of the ease with which they may be operated over short radius curves. Four-foot wheel base trucks call for outside-hung motors, which it is believed is not considered good practice. Four-foot wheel base trucks are not as easy riding as a 6-ft. wheel base and are more severe on the track than a 6-ft. wheel base. A 6-ft. wheel base truck, from the standpoint of easy riding, less wear on the track, and less maintenance, is considered more desirable.



Rolled Steel Wheels
Proposed Standard Sizes

D	T	R	H	L
33"	2½"	2½"	1 15/16" or 2 1/16"	5½"
34"	2½"	2½"	"	5½"
34"	3"	2½"	"	6"
34"	3½"	2½"	"	6"
35"	3"	3"	"	6"
35"	3½"	3"	"	6"
36"	3"	2½"	"	6"
36"	3½"	2½"	"	6"
37"	3"	3"	"	6"
37"	3½"	3"	"	6"

Relation of Tread Width
Total Width and
Flange Height

T	W	F
2½"	3 11/16"	⅝"
3"	4 3/16"	⅞"
3½"	4 11/16"	⅞"

FIG. 39.—A.E.R.E.A. recommended dimensions for rolled steel wheels.

For several years the United Traction Co., Albany, N. Y., operated trucks having a wheel base of 4 ft. 6 in. On account of this short length these trucks gave much trouble when used for the high-speed service between Albany and Troy. This bad feature was removed by lengthening the trucks to a wheel base of 5 ft. by the oxy-acetylene welding of metal at an intermediate point in the frames. The favorable results from this change confirmed company's belief that for high-speed service the wheel base of a truck should not be less than the gage of the track. The cost of lengthening a pair of trucks and of adding new steel bolsters of cored type was about $200.

Wheel Base in Interurban Service. The following data giving the practice on interurban roads are from the Electric Railway Journal, 1906:

Name of company	Type of truck	Wheel base, ft.	in.
Cleveland & Southwestern	Baldwin	6	7
Lake Shore Electric	Baldwin and Brill	7	
Eastern Ohio	Peckham	6	6
Toledo & Indiana	Peckham	6	6
Toledo & Western	Peckham and Dorner	6	
Toledo, Pt. Clinton & Lakeside	Peckham	6	6
Stark Electric	Peckham and Dorner	6	6
Canton-Akron	St. Louis	6	
Western Ohio	Peckham	6	
Ft. Wayne, Van Wert and Lima	Baldwin and Taylor	6	6
Dayton and Troy	Barney and Smith	7	
Dayton, Covington & Piqua	Barney and Smith	6	
Scioto Valley	Brill	6	6
Cincinnati, Milford & Loveland	Taylor special	4	6
Interurban Ry. & T. Cincinnati	St. Louis	4	6
Cincinnati, Georgetown & Portsmouth	St. Louis	6	
Indiana Union Traction	Baldwin	6	
Indianapolis & Northwestern	Peckham	6	6
Indianapolis & Cincinnati	Baldwin	6	5
Indianapolis, Columbus & Southern	Peckham	6	6
Terre Haute Tr. & Lgt	Baldwin	6	3
Kokomo, Marion & Western	Peckham	6	9
Ft. Wayne & Wabash Valley	Baldwin	6	6
Rapid Railway System, Detroit	Baldwin	6	6
Detroit, Ypsilanti, A. A. & J	Peckham	6	10

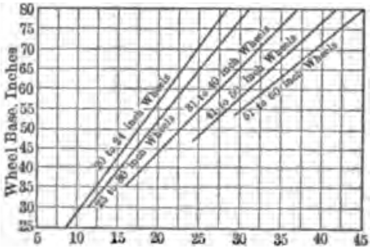


FIG. 40.—Relation between minimum curve, wheel diameter and truck wheel base.

Minimum Curve for Given Truck. Fig. 40 by Graham Bright, Electric Journal, 1911, shows the relation between wheel size, wheel base and minimum curve. These curves are plotted according to the expression

$R = \frac{W}{2 \sin a}$ (published by the Baldwin Locomotive Works)

in which R = radius of sharpest curve that can be passed, feet.
W = wheel base, feet.
a = angle which flanged wheels make with rail.

With diameter of wheel	20 in.	to 24 in.	sin a = 0.117
	25	30	= 0.107
	31	40	= 0.090
	41	50	= 0.080
	51	60	= 0.075

Ball Bearing Center Plates. The principal advantages of ball bearing center plates over smooth plate bearings are that their use is accompanied by a minimum of flange wear and energy consumption on curves. They bring about less liability to derailment and require less lubrication.

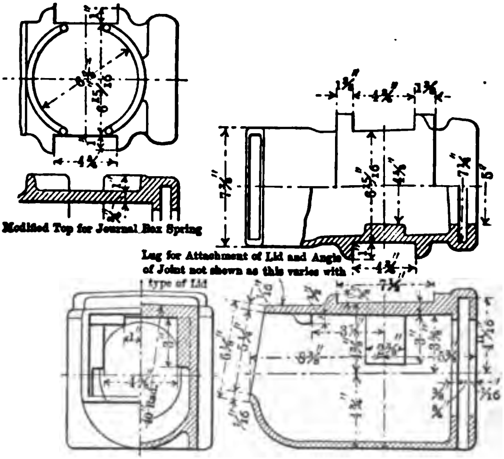
A.E.R.E.A. Standard Journal Boxes. Figs. 41 to 44, inclusive, show the A.E.R.E.A. standard journal boxes. Box tops of two designs are given. These are to fit the styles of trucks in general use on electric railways. The interiors of these boxes are arranged to accommodate the M.C.B. journal bearing wedges.

M.C.B. Standard Journal Bearing. The M.C.B. standard journal bearings are shown in Figs. 45 to 48 inclusive.

A.E.R.E.A. Standard Journal Bearing Wedges. Figs. 45 to 48, show the M.C.B. standard journal bearing wedges (journal bearing keys) which have been adopted as standard by the A.E.R.E.A. These are here shown applied to the M.C.B. standard journal bearing.

End Wear of Journal. The following is from the 1912 report of the Committee on Equipment, A.E.R.E.A. (The facts were determined by interviews with member companies): First, end wear on journals is confined almost exclusively to the M.C.B. form. Second, the stop on the end of the axle is, with the exception of the journal brass itself, subjected to the greatest amount of wear. Third, end wear is experienced chiefly where cars are operated at relatively high schedule speeds and where there are a comparatively large number of short radius curves.

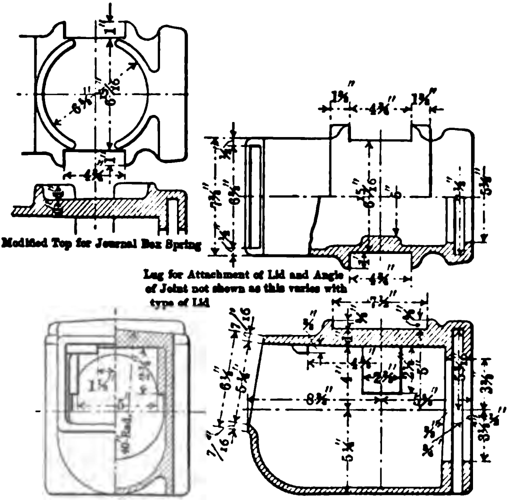
That a considerable amount of thought has been given the matter is indicated by the various methods for overcoming the difficulty, the most prominent of which are as follows: First, a hooded wedge, as illustrated in Fig. 49, with a renewable wearing plate and means provided for taking up the wear on the plate by installing shims between the plate and the inside of the hooded end of the wedge, is in fairly general use. This method offers the advantage of the use of a standard journal box, journal and wedge, the only difference being a slight modification of the wedge in the form of an extension. The second most general method of overcoming the end play is the casting of guides integral with the journal box so that an end stop of malleable iron, faced upon its bearing surface with babbitt metal, can be dropped into the guides in close contact with the end of the axle, thereby imposing the lateral thrust of the axle upon the end stop rather than on the journal brass, the end stops being renewed by babbitting. (See Fig. 50.) The chief advantages d
to this method of overcoming end play are that the stress set up



Modified Top for Journal Box Spring

Lug for Attachment of Lid and Angle of Joint not shown as this varies with type of Lid

FIG. 41.—A.E.R.E.A. standard 3¾-in. by 7-in. journal box.



Modified Top for Journal Box Spring

Lug for Attachment of Lid and Angle of Joint not shown as this varies with type of Lid

FIG. 42.—A.E.R.E.A. standard 4¼-in by 8-in. journal box.

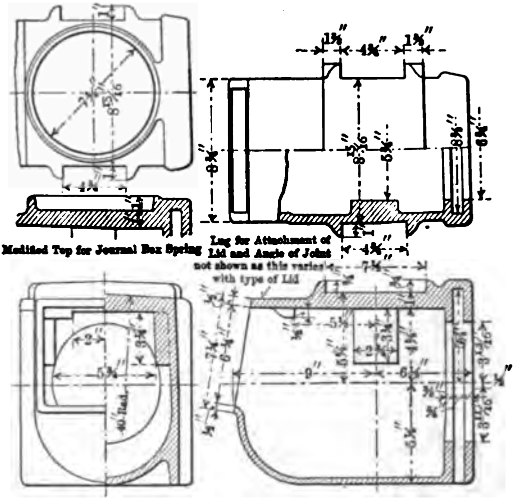

Modified Top for Journal Box Spring
Lug for Attachment of Lid and Angle of Joint not shown as this varies with type of Lid
40" Rad.

FIG. 43.—A.E.R.E.A. standard 5-in. by 9-in. journal box.

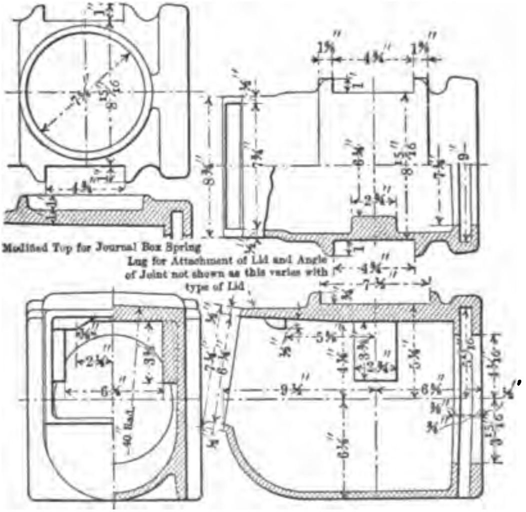
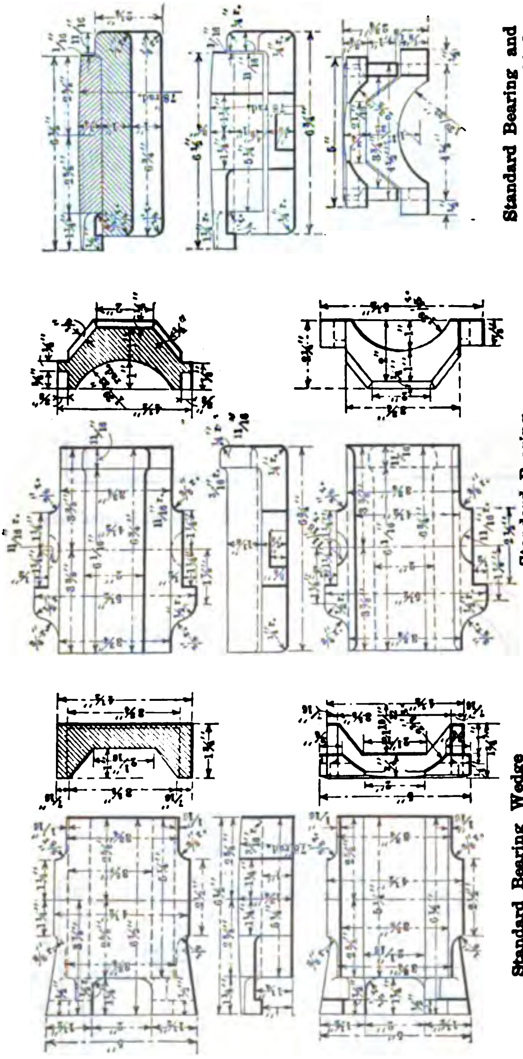

Modified Top for Journal Box Spring
Lug for Attachment of Lid and Angle of Joint not shown as this varies with type of Lid
40" Rad.

FIG. 44.—A.E.R.E.A. standard 5½-in. by 10-in. journal box.

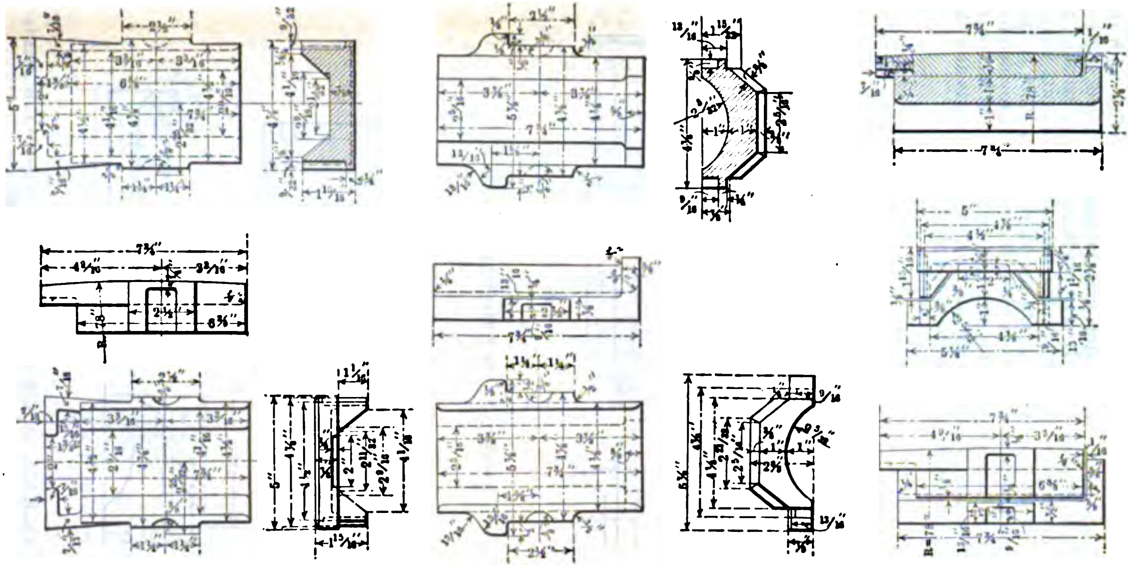


Standard Bearing and Wedge Assembled

Standard Bearing

Standard Bearing Wedge

FIG. 45.—A.E.R.E.A. (M.C.B.) standard bearing wedge M.C.B. standard bearing for 3¾-in. by 7-in. journal.



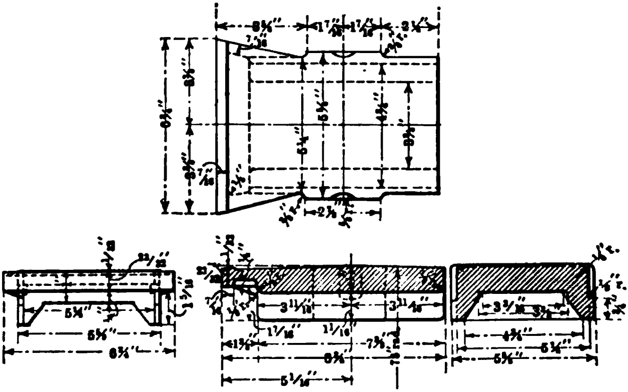
Standard Bearing Wedge

Standard Bearing

Standard Bearing and Wedge Assembled

FIG. 46.—A.E.R.E.A., (M.C.B.) standard bearing wedge M.C.B. standard bearing for 4¼-in. by 8-in. journal.

the lateral thrust of the axle is placed more nearly in line with the axle itself and that the end stop may be easily renewed without jacking up the journal box. It also serves to hold the packing in place upon the lower portions of the journal and permits better inspection of the journal box. On the other hand, its use is only permitted in new journal boxes in which the guides are provided for. These guides, however, can be arranged in the journal box with little trouble and without interfering with any other parts and the use of the end stop would then be optional.



Standard Bearing Wedge for Journal 5"x 9"

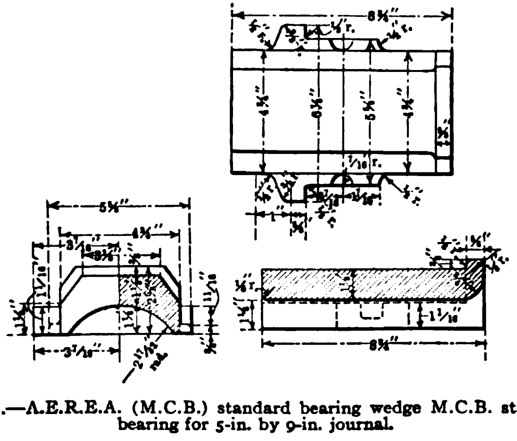


FIG. 47.—A.E.R.E.A. (M.C.B.) standard bearing wedge M.C.B. standard bearing for 5-in. by 9-in. journal.

Journal Brass for High Braking Pressure. Figs. 51 and 52 show the new journal brass, keeper and detail of axle end developed by J. S. Doyle for use on the New York Subway. This development was made because, due to the small bearing surface and great thrust

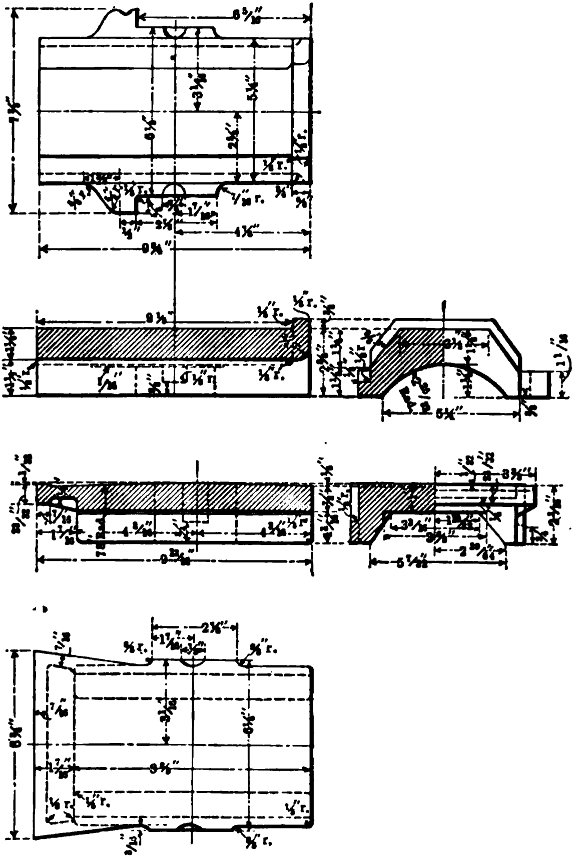


FIG. 48.—A.E.R.E.A. (M.C.B.) standard bearing wedge M.C.B. standard bearing for 5½-in. by 10-in. journal.

due to heavy and frequently applied horizontal brake pressure, the original M.C.B. brass gave much trouble from heating and crushing of the babbitt at the side of the box. The new arrangement has been successful. The main feature of this brass is the full semicircular cross-section, which gives an ample bearing on each side of the journal in order to take the horizontal thrust from the brake-shoes. The difference between it and the standard bearing is shown in Figs. 52 and 53, which give a conventional cross-section of each type of brass in its box. It thus becomes similar to the driving box brasses used on steam locomotives which have to take the thrusts of the reciprocating parts. It will be noticed in Fig. 53 that the usual collar on the journal has been turned off and that the side play of the wheels is taken up by a semicircular bronze liner riveted inside the end of the brass. The object of this is to provide a large area, accessible to the lubricant, for taking care of the end thrust from the wheels. The absence of a collar and the movement of the journal longitudinally in the brass might appear to cause the wearing of a shoulder in the brass outside of the normal position of the end of the journal. This is, however, overcome by turning a groove just inside of the end liner, which is riveted to the brass, so that the actual bearing length on the journal is constant. A side play of ¼ in. is allowed for all wheels leaving the shop. When this

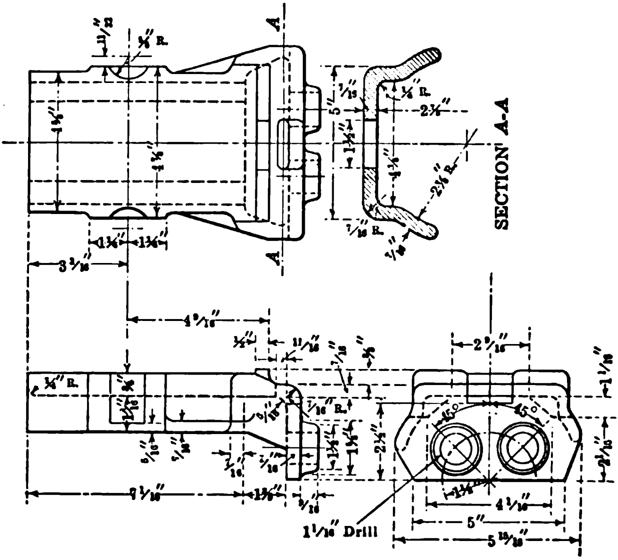


FIG. 49.—"Hooded" wedge.

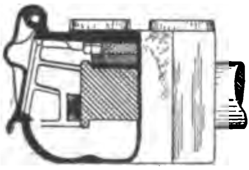
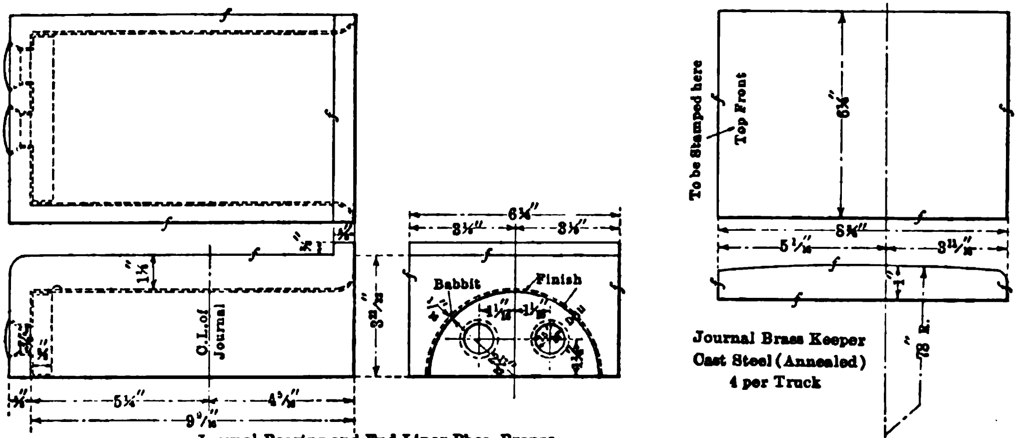


FIG. 50.—Journal box with integral guides and end stop.



Journal Bearing and End Liner-Phos. Bronze
4 per Truck

Journal Brass Keeper
Cast Steel (Annealed)
4 per Truck

FIG. 51.—Details of special journal bearing, New York subway.

increases to ⅛ in. the end liners are renewed. The brasses are tinned inside and lined with 1/16 in. of babbitt. They are then bored out two at a time in a lathe.

On the New York, Westchester and Boston Ry. similar difficulties were experienced with M.C.B. brasses and emergency braking. Fig. 54 shows a 5½ × 10 in. brass which gave satisfactory service when substituted for the M.C.B. type. This brass has approximately a semicircle of bearing surface and is provided with long side extensions to prevent shifting.

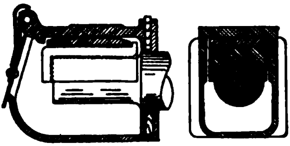


Fig. 52.—Special journal bearing, New York subway.

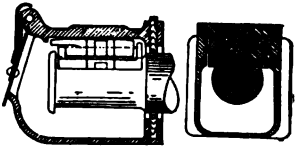


Fig. 53.—Standard journal bearing.

Lubrication of Journal Bearings. (A.E.R.E.A. Miscellaneous Methods and Practices.) Once every 30 days, providing cars do not make more than 150 miles per day, or if on a mileage basis, every 4500 miles. Journal bearings in high-speed service must be lubricated weekly when cars are making from 300 to 500 miles per day, or if on a mileage basis, every 2500 miles. In both cases the journal-box covers, springs and bolts must be examined to see that all parts are in good condition and that the cover is as nearly dust-proof as possible, and that the sponge is stirred up in the boxes, and where it has worked forward, pressed back in place, and only a sufficient amount of oil applied. This can only be done by allowing a certain amount of oil for each car or by thoroughly educating certain men to do this part of the

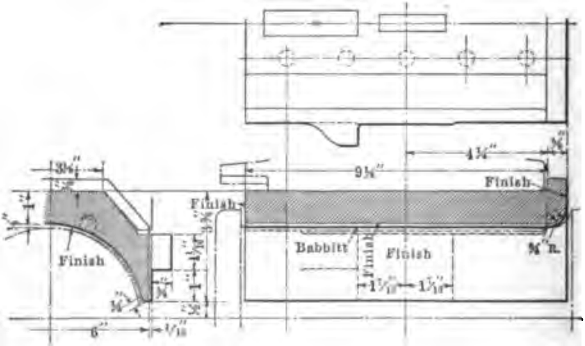


Fig. 54.—Special journal bearing, Westchester.

In the New York Subway the lubrication of the journal boxes is inspected every 1000 miles and every box is repacked after 10,000 miles of service. No free oil is ever applied. In repacking the box all the old waste is removed and the box is filled with properly worked and saturated waste, which, however, is not necessarily new. The oil consumption per journal in 1908 was about 0.4 gill per 1000 car miles for the larger cars or 0.0104 gill per 100 ton miles.

Preparation of Oil and Waste for Lubrication. (See page 323.)

Packing Tools. Fig. 55 shows packing tools used by the Chicago City Railway.

Journal Temperatures. The following comparing journal temperatures reached at different air temperatures are from tests by the use of the University of Illinois dynamometer car which is equipped with a recording thermometer, the bulb of which is inserted in a hole drilled in the body of one of the journal brasses. The car weighs 58,000 lb. and is equipped with 4¼ by 8-in. journals:

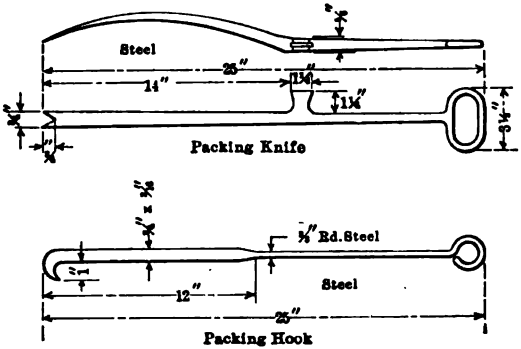


FIG. 55.—Packing tools, Chicago.

Average air temperature, deg. F.	63	9
Approximate average test speed, miles per hour	16	15
Maximum temperature attained by test-car journal, deg. F.	116	98

Flange Lubrication. A block of graphite pressed against the wheel flange or crude oil sprayed upon the wheel flange has been used to lubricate the flanges. Fig. 56 shows the general scheme of the electropneumatic apparatus developed by W. D. Hall for use in the electric locomotive service of the St. Clair Tunnel. Filtered reclaimed armature bearing oil is used as the lubricant. The following relative to this installation is from the Electric Railway Journal, 1912: "The oil for this lubricator is contained in an air-tight receptacle of 1-quart capacity, whence it is led to the wheel flanges by pipes and sprayed upon the flanges by jets of air. The air is supplied from the main reservoir by a ¼-in. pipe which is connected to the oil receptacle above the surface of the oil. A branch of this pipe is connected to the oil delivery pipe which leads to the flanges. When used with electrical equipment air is controlled by an electric push button so that the lubricant is applied only when needed, as on curves. This apparatus has been in successful operation since July 10, 1910. The six electric locomotives to which it has been applied haul 1000-ton trains up and down 2 per cent. grades on which flange wear had been heavy owing to the many curves and the rather low center of gravity of the locomotives. This lubricator has so improved conditions that 50,000 miles and more are made between wheel tire turnings. This means that the wheels can be removed for turning at the same time that the armature is removed for commutator dressing. The former mileage made between tire turnings was from 12,000 to 25,000 miles." On the Baltimore & Ohio and the Pennsylvania locomotives a sight feed lubricator is located in the cab. The temperature of the air and oil is raised by passing them through an electric heater. The oil is led to the wheel flange by pipes and is spread upon the flanges by air supplied from the main reservoir. Investigators on the Pennsylvania Lines west of Pittsburgh concluded that flange lubrication would cause an appreciable saving in flange wear on curves of 4 deg. or more. Records of rail renewal on the Sierra Nevada division of the Southern Pacific Railway, where all the locomotives are equipped with flange oilers, show that since the latter have been in service the average life of the outside rail on all curves of more than 5 deg. has been increased from 12 months to 32 months, while the average life of the inside rail on the same curves has been increased from 13 months to 33 months in spite of the fact that the rails are now removed with a smaller percentage of wear than was formerly the case. At the same time the average daily tonnage has increased 47 per cent. as compared with the 3 years prior to May, 1908, when the flange oilers were installed.

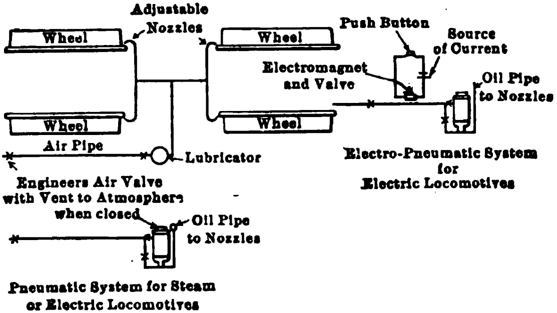

Adjustable Nozzles
Wheel
Wheel
Push Button
Source of Current
Electromagnet and Valve
Oil Pipe to Nozzles
Wheel
Wheel
Air Pipe
Lubricator
Electro-Pneumatic System for Electric Locomotives
Engineers Air Valve with Vent to Atmosphere when closed
Oil Pipe to Nozzles
Pneumatic System for Steam or Electric Locomotives

FIG. 56.—Flange lubricator, Grand Trunk Ry.

SECTION VIII

BRAKING

Brake-shoe Pressure. The maximum retardation which may be utilized in stopping a train by means of brakes is that which is realized by so applying brake-shoes to all the wheels that the resulting brake-shoe friction shall be uniform and just insufficient to overcome the static rail friction or adhesion. Thus the utilization of the entire retarding force available as rail friction or adhesion involves the application of a brake-shoe pressure which shall (*a*) diminish as declining speed causes the coefficient of friction to increase; which shall (*b*) increase as increased distance of frictional contact causes the coefficient of friction to decline, and which shall (*c*), when diminishing or increasing for such purposes, further diminish or increase as reduction or increase of pressure itself causes the coefficient of friction correspondingly to increase or decline. It is impracticable to so regulate the brake-shoe pressure that it will at any instant be equal to the resultant of the above three, but since this resultant continues to diminish during the process of bringing the train to rest, the maximum possible retarding effect may be approximated by so diminishing the brake-shoe pressure toward the completion of the stop that the wheels will not be caused to slide.

Factors Controlling Length of Stop. The general factors which determine the distance traveled by a train while it is being brought to rest on a tangent level track are: (*a*) speed of the train at the beginning of the braking period; (*b*) coefficient of adhesion between wheel and rail (rail friction); (*c*) coefficient of brake-shoe friction; (*d*) maximum brake cylinder force; (*e*) time required to attain this force; (*f*) efficiency of brake rigging in multiplying and transmitting this force to the brake-shoe.

Importance of High Rate of Retardation. In long runs, the braking rate is of little moment, but in short runs it becomes an important factor and, as in subway work, may be of maximum importance. In general, a high braking rate is advantageous because it allows more coasting in any run which means an earlier point of cut-off, resulting in lower energy consumption and less heating of the motors than would accompany a low rate of braking. Fast braking thus tends to minimize the size of motor for a given service. The minimum length of a block and the consequent minimum headway is equal to the minimum distance in which a train can be brought to rest. Thus, increasing the rate of braking decreases the allowable headway and increases the capacity of the track.

High Speeds and Wheel Failures. In the use of high speeds care should be taken that the conditions of braking are such that they will not be dangerous to car wheels. The temperature attained at the wheel tread during braking depends upon the pressure at which the brake-shoe is applied, the speed at which the wheel is turning, and the duration of the brake application. When the wheel is turning at high speed and the brake-shoes are applied with great pressure, the metal at and near the surface of the tread suddenly becomes much hotter than that a short distance in. Great thermal stresses are thus set up in the wheel and these may cause fracture.

Coefficient of Friction at Various Speeds

CAST-IRON BRAKE-SHOES ON STEEL TIRES (GALTON-WESTINGHOUSE TESTS, PROCEEDINGS OF THE INSTITUTION OF MECHANICAL ENGINEERS, 1879)

Number of experiments from which the mean is taken	Speed		Coefficient of friction		
	Miles per hour	Feet per second	Extremes observed		Mean
			Maximum	Minimum	
12	60	88	0.123	0.058	0.074
67	55	81	0.136	0.060	0.111
55	50	73	0.153	0.050	0.116
77	45	66	0.179	0.083	0.127
70	40	59	0.194	0.088	0.140
80	35	51	0.197	0.087	0.142
94	30	44	0.196	0.098	0.164
70	25	36½	0.205	0.108	0.166
69	20	29	0.240	0.133	0.192
78	15	22	0.280	0.131	0.223
54	10	14½	0.281	0.161	0.242
28	7½	11	0.325	0.123	0.244
20	Under 5	Under 7	0.340	0.156	0.273
	Just moving	Just moving			0.330
Fleeming Jenkin (steel on steel)	0.0002 to 0.0080		0.337	0.365	0.351

Rennie. Static friction under
Pressure of 180 lb. per square inch..........0.300
Pressure of 336 lb. per square inch..........0.347

From the above values Mr. R. A. Parke has developed the following formulas to represent the law of variation of the coefficient of friction with speed.

From the mean values $$f = \frac{0.326}{1 + 0.03532\,S}$$

from the maximum values $$f = \frac{0.382}{1 + 0.02933\,S}$$

where f = coefficient of friction
S = speed in miles per hour.

The latter formula gives values corresponding more nearly to recent experiments.

The following table furnishes a comparison of the values of the coefficient of friction as calculated by the above formulas, with those secured by test (see above table).

Speed, miles per hour	Coefficient of friction			
	Mean		Maximum	
	Calculated	Observed	Calculated	Observed
0	0.326	0.330	0.382	....
5	0.277	0.273	0.333	0.340
10	0.241	0.242	0.295	0.281
15	0.213	0.223	0.265	0.280
20	0.191	0.192	0.241	0.240
25	0.173	0.166	0.220	0.205
30	0.158	0.164	0.203	0.196
35	0.146	0.142	0.188	0.197
40	0.135	0.140	0.176	0.194
45	0.126	0.127	0.165	0.179
50	0.118	0.116	0.155	0.153
55	0.111	0.111	0.146	0.136
60	0.105	0.074	0.138	0.123
65	0.099	....	0.131	....
70	0.094	....	0.125	....
80	0.085	....	0.114	....
90	0.078	....	0.106	....
100	0.072	....	0.097	....

Relation of Coefficient of Friction between Wheel and Rail to the Coefficient of Friction between Brake-shoe and Wheel and the Effect of Sliding. In the Galton-Westinghouse tests it was found that when the brake-shoe friction overcame the rail friction and caused the wheels to slide upon the rails, the coefficient of rail friction immediately began to decline and then varied inversely as the speed, in much the same way as brake-shoe friction. It was found to have a value of less than one-third the coefficient of brake-shoe friction when the brake-shoe pressure was such as to allow the wheel to continue revolving. From this, the retarding effect of a wheel sliding upon a rail would be less than one-third the maximum available when the wheels are allowed to revolve without sliding.

COEFFICIENT OF FRICTION BETWEEN STEEL TIRES AND STEEL RAIL—WHEEL SLIDING. (GALTON-WESTINGHOUSE TESTS)

Speed, miles per hr.	Coefficient of friction
Just coming to rest	0.242
6.8	0.088
13.6	0.072
27.3	0.070
34.1	0.065
40.9	0.057
47.7	0.040
54.5	0.038
60.0	0.027*

The rail friction is very materially affected by the condition of the rail, being greatest when the rail is perfectly dry or very wet

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* This is from the mean of three experiments only.

(as when washed by a hard rain) and least when the rail is quite moist; but by the use of sand upon the rails, the effect of moisture is practically eliminated. (See Coefficient of Adhesion, p. 139.)

Coefficient of Brake-shoe Friction as Affected by Distance of Application. Capt. Galton stated that a decrease in the coefficient of brake-shoe friction results from the time during which the brakes have been kept applied, irrespective of any change in speed. He gave the following table and explained that the values given in the column headed "Commencement of experiment" are somewhat different from those that have been given in the table "Coefficient of Friction at Various Speeds . . .," p. 468, because they resulted from the average of fewer experiments, but that the effect of time reducing the coefficient of friction may be accepted as correct.

COEFFICIENT OF BRAKE-SHOE FRICTION AS AFFECTED BY TIME (GALTON)

Speed, miles per hour	Coefficient of friction				
	Commencement of experiment	After 5 seconds	After 10 seconds	After 15 seconds	After 20 seconds
20	0.182	0.152	0.133	0.116	0.099
27	0.171	0.130	0.119	0.081	0.072
37	0.152	0.096	0.083	0.069	....
47	0.132	0.080	0.070	....	....
60	0.072	0.063	0.058	....	....

The following is from a paper by R. A. Parke, A.I.E.E., 1902: "It was assumed by Capt. Galton that the decline of the friction is as the increase of the time of contact, but a careful analysis of the results shows that it is a function of the product of the speed and the time, or of the distance through which the shoe rubs upon the wheel." The following formula was developed by Mr. Parke in an endeavor to show the relation of the coefficient of brake-shoe friction at any point during the application of the brake-shoe to the initial coefficient of brake-shoe friction at the speed and pressure at which the brake-shoe was first applied to the wheel and the distance traveled by the wheel during which the brake-shoe has been applied to the wheel:

$$h = \frac{1 + 0.0004722l}{1 + 0.002390l} f$$

in which h = coefficient of brake-shoe friction at instant considered
l = distance wheel has traveled in frictional contact with the brake-shoe, feet
f = coefficient of brake-shoe friction at speed and pressure at which brake-shoe was applied at the beginning of the distance l.

Mr. S. W. Dudley, in a paper before the A.S.M.E., 1914, on the Pennsylvania-Westinghouse Brake Tests, 1913, stated that factors such as speed, pressure and time of action, which are ordinarily considered to cause variations in cast-iron brake-shoe performance, are effective chiefly as they affect the temperature of the working metal of the brake-shoe and wheel.

Retardation Produced by a Given Retarding Force. The rate of retardation may be approximated by the following formula:

$$a = 0.01098\frac{k(F + F_1)}{W}$$

in which

a = rate of retardation of train, miles per hour per second

k = ratio of linear inertia to total inertia of train (see page 170)

W = weight of train, tons

F = total retarding force applied to train, pounds

$= Ph$

or

$= 2000bW$

P = total braking pressure applied normally to wheel treads by brake-shoes, pounds

h = coefficient of brake-shoe friction

b = ratio of retarding force produced by brake-shoes to total weight of train

F_1 = combined train, track grade and curve resistance

$= fW$

f = train resistance, pounds per ton weight of train (see page 146).

For a more rapid, very rough approximation in ordinary service, neglecting the energy due to the rotation of the wheels and armatures and the energy required to overcome train resistance, the formula is:

$$a = 0.011\frac{F}{W}$$

or

$$= 22b$$

in which the symbols have the same significance as above.

Distance Traveled by Train During Application of a Constant Retarding Force. If a constant retarding force is applied to a train

$$l = 0.733\frac{S^2}{a}$$

or

$$= 66.8\frac{WS^2}{k(F + F_1)}$$

in which l = distance traveled by train in coming to rest, feet

S = speed of train at beginning of period, miles per hour. Other symbols as in preceding paragraph.

Neglecting the energy of rotation of wheels and armatures, the formula is

$$l = 0.0333\frac{S^2}{b}$$

$$= \frac{S^2}{30b}$$

Braking Distance Chart. The chart, Fig. 1, by Mr. Gaylord Thompson, A.E.R.E.A. 1914 Committee on Block Signals, gives a graphical approximation of the distance and time in which a train will be brought to rest when retarded at a constant rate. Example: Assume that such a braking force has been applied to a car as to produce a retardation of 3 miles per hour per second. It is desired to know how long a time will be required for the car to come to a stop and in what distance it will do so from a speed of, say, 50 miles per hour. The solid line for 3 miles per hour per second shows that a speed of 50 miles per hour corresponds to a braking distance of 600 ft. This is indicated by the point *A*. Directly below *A*, at the point where a vertical line dropped from *A* intersects the distance-time curve for 3 miles per hour per second and reading on the right-hand scale, we find that the time required for the stop is 16.5 seconds. That is, with this rate of retardation it will take 16.5 seconds to stop a car running at 50 miles per hour, and in stopping it, a distance of 600 ft. will be covered. A similar procedure shows that from 60 miles per hour the same braking rate will stop the car in 20 seconds and 880 ft.

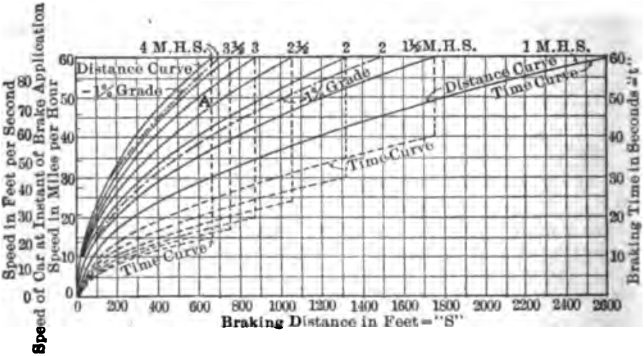

FIG. 1.—Distances and time for braking.

Braking Distance Including Application Time. Neglecting the energy of rotation of wheels and armatures, neglecting train resistance, and considering the time required for the brakes to become effective, when the wheels do not slip

$$l = 1.467St + \frac{S^2}{30Peh}$$

in which l = length of stop, feet
S = speed of train at beginning of stop, miles per hour
t = time at beginning of the stop during which the brakes are to be considered as having no effect, seconds. The value of t depends upon the equipment. In the Pennsylvania-Westinghouse 1913 tests on a twelve-car train it was found to range from 2.0 to 2.5 seconds

for the quick action automatic (PM) brake and from 0.70 to 0.85 seconds for the electro-pneumatic (UC) brake

P = nominal per cent. braking power (decimally expressed) corresponding to the average cylinder pressure existing for that portion of the stop after the brake is considered fully applied. (The nominal per cent. braking power is the ratio of the total shoe pressure, calculated from the full service brake cylinder pressure, to the weight of the car, expressed in per cent.)

e = efficiency of brake rigging (decimally expressed)

h = coefficient of brake-shoe friction.

In the absence of a satisfactory separate determination of the values of e and h, Mr. S. W. Dudley, A.S.M.E., 1914, used the following values of eh as determined in the Pennsylvania-Westinghouse 1913 tests.

Values of eh

Kind of brake rigging		Clasp brake		Single shoe*	
Type of brake shoe		Plain	Flanged	Plain	Flanged
Speed, miles per hour	Nominal per cent. braking power				
30	125	0.141	0.169	0.108	0.112
	150	0.129	0.154	0.099	0.103
	180	0.118	0.141	0.090	0.094
60	125	0.103	0.122	0.074	0.090
	150	0.094	0.112	0.068	0.082
	180	0.086	0.102	0.062	0.075
80	125	0.092	0.109	0.070	0.074
	150	0.084	0.100	0.064	0.068
	180	0.077	0.092	0.059	0.062

In this test a single car (locomotive not attached) was stopped from an initial speed of 60 miles per hour in 725 ft. This was the shortest 60 miles per hour emergency stop made. The equipment was electropneumatic, clasp brake, flanged brake-shoes, using 180 per cent. braking power. Under the same conditions the shortest stop from 80 miles per hour was 1422 feet.

Braking Distance, Single Car Tests. Tables, I, II and III, (pp. 474–478) give the braking distances on dry rail as obtained by tests in charge of Mr. George L. Fowler on the Brooklyn Rapid Transit System. The series included tests of five different makes of hand brakes and air brakes adjusted to four different ratios or pressures, three different weights of cars, with and without sand. With the air brake the car was stopped by the "service" application and by the "emergency" application. Tests were made on an empty car, on a car loaded with sand to represent a seated load

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* Value of data uncertain, due to non-uniform brake-shoe conditions.

TABLE I.—No. 400 SERIES. BRAKING DISTANCES, VARIOUS LOADS AND SPEEDS. DRY RAIL

Car number	432	432		432		432		432	
Brakes	Air, 85 %	Air, 85 %		Air, 90 %		Air, 95 %		Air, 100 %	
	No sand	No sand	Sand	No sand	Sand	No sand	Sand	No sand	Sand
Empty car:									
Date	12/19/11	4/6/12		4/6/12		4/7/12		4/7/12	
Weight, lb.	30,300	30,300		30,300		30,300		30,300	
Distance:									
5 M.P.H.	4′ 6″	7′ 4″	7′ 3″	6′ 3″	6′ 3″	5′ 5″	6′ 6″	6′ 1″	5′ 9″
10 M.P.H.	18′ 11″	26′ 11″	25′ 8″	25′ 0″	21′ 9″	25′ 3″	22′ 11″	22′ 5″	23′ 1″
15 M.P.H.	48′ 10″	57′ 4″	53′ 2″	54′ 1″	53′ 9″	56′ 10″	49′ 0″	53′ 3″	46′ 5″
20 M.P.H.	85′ 1″	99′ 8″	103′ 5″	95′ 6″	90′ 2″	97′ 7″	88′ 3″	88′ 0″	91′ 3″
Seated load:									
Date	12/17/11	4/8/12		4/8/12		4/8/12		4/7/12	
Weight, lb.	40,100	40,100		40,100		40,100		40,100	
Distance:									
5 M.P.H.	7′ 2″	6′ 2″	7′ 3″	5′ 10″	6′ 0″	5′ 1″	6′ 2″	6′ 3″	6′ 9″
10 M.P.H.	29′ 9″	25′ 1″	22′ 8″	23′ 6″	22′ 8″	21′ 9″	21′ 7″	27′ 6″	24′ 10″
15 M.P.H.	63′ 3″	55′ 11″	49′ 9″	52′ 10″	51′ 1″	50′ 7″	47′ 8″	58′ 7″	55′ 6″
20 M.P.H.	108′ 6″	102′ 3″	94′ 4″	89′ 1″	89′ 3″	89′ 1″	86′ 6″	102′ 9″	104′ 4″
Standing load:									
Date	12/18/11	4/11/12		4/11/12		4/8/12		4/11/12	
Weight, lb.	45,300	45,300		45,300		45,300		45,300	
Distance:									
5 M.P.H.	6′ 7″	6′ 1″	6′ 10″	6′ 8″	7′ 1″	6′ 0″	6′ 2″	6′ 4″	6′ 4″
10 M.P.H.	26′ 3″	26′ 4″	24′ 6″	23′ 11″	25′ 9″	23′ 1″	23′ 7″	24′ 11″	24′ 4″
15 M.P.H.	65′ 11″	56′ 3″	55′ 6″	55′ 8″	55′ 5″	53′ 5″	50′ 1″	58′ 9″	55′ 9″
20 M.P.H.	108′ 5″	117′ 5″	105′ 10″	101′ 3″	102′ 1″	97′ 9″	96′ 7″	104′ 7″	102′ 0″

Car number	454	454	454	448	441	422	432	453
Brakes	"A" No sand	"A" No sand	"A" Sand	"B" No sand	"C" No sand	"D" No sand	"E" No sand	"E" No sand
Empty car:								
Date	1/26/12	4/12/12	4/12/12	1/1/12	1/4/12	11/30/12	11/23/12	11/29/12
Weight, lb.	28,760	28,760	28,760	28,200	28,500	28,200	30,300	28,000
Distance:								
5 M.P.H.	3′ 6″	5′ 4″	4′ 8″	3′ 8″	5′ 7″	6′ 8″	8′ 0″	6′ 0″
10 M.P.H.	18′ 3″	25′ 3″	24′ 10″	18′ 10″	26′ 7″	24′ 5″	27′ 8″	23′ 7″
15 M.P.H.	44′ 1″	52′ 6″	52′ 0″	44′ 4″	51′ 7″	51′ 10″	69′ 10″	50′ 5″
20 M.P.H.	81′ 6″	95′ 2″	98′ 8″	82′ 10″	100′ 4″	95′ 10″	129′ 3″	101′ 10″
Seated load:								
Date	1/25/12	4/12/12	4/12/12	1/1/12	1/2/12	11/30/12	11/28/12	11/29/12
Weight, lb.	38,500	38,500	38,500	38,000	38,300	37,900	40,100	37,800
Distance:								
5 M.P.H.	6′ 1″	7′ 0″	6′ 10″	5′ 6″	6′ 9″	8′ 2″	8′ 5″	7′ 10″
10 M.P.H.	24′ 0″	26′ 3″	26′ 6″	25′ 6″	27′ 2″	29′ 8″	30′ 5″	31′ 8″
15 M.P.H.	51′ 3″	60′ 10″	57′ 0″	54′ 4″	57′ 1″	60′ 8″	51′ 2″	63′ 1″
20 M.P.H.	99′ 5″	107′ 9″	108′ 1″	106′ 2″	115′ 11″	110′ 4″	137′ 8″	118′ 6″
Standing load:								
Date	1/26/12	4/12/12	4/12/12	1/1/12	1/2/12	11/30/12	11/28/12	11/29/12
Weight, lb.	43,700	43,700	43,700	43,200	43,500	43,100	45,300	43,000
Distance:								
5 M.P.H.	5′ 8″	7′ 5″	7′ 5″	7′ 11″	6′ 10″	8′ 6″	8′ 3″	9′ 8″
10 M.P.H.	23′ 9″	29′ 6″	28′ 0″	32′ 3″	29′ 4″	34′ 5″	35′ 6″	34′ 10″
15 M.P.H.	55′ 2″	62′ 10″	62′ 9″	69′ 0″	70′ 7″	68′ 3″	82′ 4″	73′ 9″
20 M.P.H.	107′ 1″	112′ 10″	116′ 8″	129′ 10″	126′ 5″	128′ 7″	152′ 7″	133′ 5″

Note: Brakes "A," "B," "C," "D," and "E," are hand brakes.

TABLE II.—NO. 2700 SERIES, SEMI-CONVERTIBLE CARS. BRAKING DISTANCES, VARIOUS LOADS AND SPEEDS. DRY RAIL

Car number	2720		2721				2722			
Brake	Air 85 %	"D"	Air, 85 %		"C"		Air, 85 %		"B"	
	No sand	No sand	No sand	Sand	No sand	Sand	No sand	Sand	No sand	Sand
Empty car:										
Date	1/20/12		3/18/12		3/18/12		4/4/12		4/4/12	
Weight, lb.	31,300		31,500		31,500		31,200		31,200	
Distance:										
5M.P.H.	7' 5"	8' 6"	7' 8"	7' 3"	7'11"	....	7'10"	6' 0"	6'11"	....
10M.P.H.	30' 8"	31' 11"	27' 2"	27'11"	33' 0"	....	24' 4"	24' 3"	25' 6"	....
15M.P.H.	62' 7"	70' 3"	61' 7"	59'11"	66' 5"	64' 9"	57'11"	53' 2"	57' 8"	57' 4"
20M.P.H.	109' 0"	118' 2"	108' 3"	103'10"	110' 2"	119' 7"	93'11"	91' 9"	98' 9"	100' 7"
Seated load:										
Date	1/20/12	1/21/12	3/19/12		3/19/12		4/5/12		4/4/12	
Weight, lb.	36,700		37,000		37,000		36,600		36,600	
Distance:										
5M.P.H.	7' 3"	8' 0"	9' 5"	9' 6"	9'10"	....	8' 5"	7' 8"	8' 3"	....
10M.P.H.	23'10"	31' 6"	33' 5"	33' 1"	35' 1"	....	29' 6"	28' 3"	30' 9"	....
15M.P.H.	58' 3"	66' 0"	71' 1"	71' 3"	84' 0"	75'11"	60' 0"	61' 8"	66' 9"	60' 9"
20M.P.H.	120'10"	137' 5"	121'10"	121' 1"	127' 8"	139' 4"	108' 6"	104' 9"	110'10"	109' 0"
Standing load:										
Date	1/21/12		2/12/12		2/12/12		4/5/12		4/5/12	
Weight, lb.	43,300		43,500		43,500		43,200		43,200	
Distance:										
5M.P.H.	8'10"	9' 5"	10' 8"	....	10' 5"	....	10' 0"	9'10"	10'11"	....
10M.P.H.	33' 0"	34' 1"	35' 8"	....	34' 7"	....	34'11"	32' 0"	36' 9"	....
15M.P.H.	73' 0"	92' 0"	67' 6"	....	77' 2"	....	73' 5"	64' 6"	91' 0"	81' 1"
20M.P.H.	127' 3"	162'10"	120' 5"	....	133' 3"	....	138' 9"	136'10"	144'11"	165'10"

NOTE: Brakes "B," "C," and "D" are hand brakes.

Car number	2723											
Brakes	Air 85%		Air 90%		Air 95%		Air 100%		Air 85%		"A"	
	No sand	Sand	No sand	Sand	No sand	Sand	No sand	Sand	No sand	Sand	No sand	Sand
Empty car:												
Date	3/19/12	2/12/12	3/31/12		3/30/12		3/31/12		4/24/12	4/21/12	4/24/12	4/21/12
Weight, lb.	31,400		31,400		31,400		31,400		31,400		31,400	
Distance:												
5 M.P.H.	8′ 5″	....	5′ 9″	6′ 0″	5′ 0″	5′ 8″	5′ 10″	6′ 4″	8′ 10″	9′ 4″	6′ 6″	7′ 6″
10 M.P.H.	29′ 2″	....	23′ 8″	23′ 11″	22′ 10″	23′ 5″	28′ 7″	24′ 0″	29′ 8″	29′ 2″	28′ 4″	26′ 11″
15 M.P.H.	57′ 1″	....	59′ 7″	49′ 2″	46′ 9″	49′ 0″	52′ 0″	49′ 3″	63′ 0″	58′ 8″	64′ 5″	57′ 8″
20 M.P.H.	111′ 11″	92′ 8″	96′ 1″	88′ 8″	92′ 9″	86′ 4″	96′ 9″	87′ 4″	102′ 10″	99′ 0″	115′ 2″	106′ 11″
Seated load:												
Date	3/27/12		3/30/12		3/30/12		3/27/12		4/24/12	4/21/12	4/24/12	4/21/12
Weight, lb.	36,800		36,800		36,800		36,800		36,700		36;700	
Distance:												
5 M.P.H.	6′ 6″	7′ 3″	7′ 5″	7′ 4″	6′ 6″	6′ 8″	6′ 11″	6′ 6″	10′ 1″	10′ 0″	9′ 3″	8′ 3″
10 M.P.H.	28′ 8″	24′ 7″	28′ 2″	25′ 10″	29′ 1″	23′ 10″	26′ 6″	23′ 0″	32′ 7″	30′ 6″	32′ 0″	29′ 1″
15 M.P.H.	59′ 3″	52′ 4″	64′ 11″	53′ 10″	53′ 2″	50′ 5″	56′ 7″	52′ 1″	65′ 8″	64′ 0″	66′ 9″	65′ 3″
20 M.P.H.	104′ 11″	98′ 0″	111′ 5″	97′ 10″	103′ 7″	95′ 4″	105′ 8″	92′ 7″	116′ 4″	112′ 7″	116′ 10″	118′ 9″
Standing load												
Date	3/26/12		3/26/12		3/26/12		3/27/12		4/21/12		4/21/12	
Weight, lb.	43,400		43,400		43,400		43,400		43,400		43,400	
Distance:												
5 M.P.H.	7′ 3″	8′ 6″	6′ 4″	5′ 9″	8′ 0″	8′ 6″	8′ 1″	8′ 0″	11′ 7″	10′ 7″	9′ 4″	9′ 2″
10 M.P.H.	31′ 1″	24′ 10″	25′ 1″	22′ 8″	31′ 4″	26′ 1″	26′ 7″	29′ 2″	34′ 9″	32′ 10″	32′ 5″	33′ 6″
15 M.P.H.	65′ 4″	55′ 9″	64 2″	53′ 3″	66′ 6″	56′ 8″	66′ 11″	57′ 1″	70′ 10″	71′ 4″	70′ 6″	72′ 11″
20 M.P.H.	110′ 0″	119′ 2″	104′ 4″	110′ 6″	114′ 2″	107′ 5″	122′ 9″	109′ 8″	127′ 4″	128′ 8″	136′ 5″	128′ 0″

NOTE: Brake "A" is hand brake.

TABLE III.—NO. 2500 SERIES SEMI-CONVERTIBLE CARS. BRAKING DISTANCES, VARIOUS LOADS AND SPEEDS, DRY RAIL

Car number	2500		2500		2500		2500		2501		2584	
Brake	Air, 85%		Air, 90%		Air, 95%		Air, 100%		"E"		"A"	
	No sand	Sand	No sand	Sand	No sand	Sand	No sand	Sand	No sand	Sand	No sand	Sand
Empty car:												
Date	3/11/12		3/14/12		3/11/12		3/14/12		2/29/12		3/31/12	
Weight, lb.	38,300		38,300		38,300		38,300		36,600		36,600	
Distance:												
5 M.P.H.	5′ 4″	6′ 4″	5′ 4″	5′ 5″	4′11″	5′ 0″	5′ 8″	5′ 4″	4′ 9″	....	5′ 0″	4′ 7″
10 M.P.H.	18′10″	19′ 7″	19′ 6″	18′11″	18′11″	18′10″	19′11″	19′ 8″	23′ 4″	....	20′10″	20′10″
15 M.P.H.	41′ 2″	42′11″	43′ 1″	40′ 6″	41′10″	40′ 5″	40′ 4″	41′ 6″	45′ 9″	47′ 6″	48′ 4″	44′ 5″
20 M.P.H.	74′ 6″	80′ 3″	66′11″	75′ 4″	73′ 2″	77′10″	74′ 7″	76′ 6″	82′ 6″	86′ 2″	82′ 5″	87′10″
Seated load:												
Date	3/14/12		3/14/12		3/16/12		3/16/12		2/29/12		4/1/12	
Weight, lb.	43,800		43,800		43,800		43,800		41,800		42,000	
Distance:												
5 M.P.H.	6′ 8″	6′10″	5′ 2″	5′ 5″	5′ 9″	6′ 1″	4′ 7″	5′ 1″	5′ 4″	....	6′ 9″	5′11″
10 M.P.H.	22′ 6″	24′ 0″	20′ 0″	19′ 8″	22′10″	22′ 9″	18′ 9″	21′ 8″	22′ 6″	....	22′10″	22′ 6″
15 M.P.H.	47′10″	49′ 8″	46′ 5″	46′ 1″	49′ 5″	52′ 1″	43′ 0″	45′ 2″	48′ 1″	45′ 1″	50′ 9″	47′ 6″
20 M.P.H.	87′ 2″	91′ 1″	81′ 0″	83′ 0″	84′ 3″	91′ 6″	80′10″	80′ 5″	84′ 4″	79′11″	88′ 6″	87′10″
Standing load:												
Date	3/17/12		3/17/12		3/17/12		3/17/12		2/29/12		4/1/12	
Weight, lb.	50,400		50,400		50,400		50,400		48,600		48,600	
Distance:												
5 M.P.H.	8′ 4″	7′ 7″	8′ 3″	6′ 9″	6′ 8″	6′ 1″	6′ 5″	6′ 4″	5′ 4″	....	6′ 6″	6′ 9″
10 M.P.H.	28′ 0″	32′ 5″	24′ 9″	25′ 0″	22′ 0″	25′11″	21′ 8″	22′ 0″	24′ 3″	....	24′ 8″	24′10″
15 M.P.H.	61′ 9″	67′ 8″	55′ 5″	54′ 7″	51′ 5″	54′ 3″	47′ 8″	48′ 0″	51′ 7″	52′ 1″	51′ 2″	53′ 4″
20 M.P.H.	107′ 0″	116′ 8″	100′ 9″	107′10″	92′ 3″	98′ 6″	83′11″	92′ 6″	94′ 6″	91′10″	93′ 5″	94′ 6″

NOTE: Brakes "A" and "E" are hand brakes.

and on a car loaded to represent a standing load. The car was stopped when running at 5, 10, 15 and 20 miles per hour. Three stops were made at each speed and load, making thirty-six stops for each complete test on each brake and method of braking.

Hand Brakes vs. Air Brakes. Hand brakes are satisfactory for ordinary operation on light cars and should be supplied for emergency on all cars. However, as the weight of a car increases the difficulty of control increases till it reaches such a value that power is necessary for ordinary braking. Just what weight should divide the hand brake class from the power brake class has been a matter of much investigation, many tests and disagreements. The difficulties of such tests are briefly summed up by Mr. J. N. Dodd of the Public Service Commission, First District, New York, as follows:

"In the course of this search it became apparent that tests do not always furnish a reliable criterion of the relative value of different brakes. They merely state the stopping distance of the car under the particular conditions that obtained at the time of the test. Most of the conditions that affect this distance vary widely. Among these varying conditions may be mentioned the brake-shoe adjustment, the weight of the car, the condition of the rail, and the human element. Most of these factors vary widely also during the course of the day, and each of them may change independently of any of the others. Thus, on account of the wear of the brake-shoes, the brake adjustment may change materially even in the course of a single trip. The weight of the car is continually changing, owing to the varying number of passengers. The condition of the rail may alter entirely in the course of a few seconds. This change is often such that a visual inspection of the rail fails to reveal its quality. Thus, a wet rail may provide an ideal surface for stopping a car quickly, or it may offer the reverse. In the same way, though not to the same extent, the distance in which a car may be stopped on a dry rail varies according to whether the rail is clean or covered with dust or dirt. For this reason it is impossible to be sure that the rail conditions are the same in tests on two different brakes or that the rail conditions at the time of the test correctly represent average rail conditions under which the car must operate throughout the year. The human element also is extremely variable. In actual service there are many strong motormen and many who are physically weak, many who are intelligent and mentally alert and many the reverse, many in fresh physical and mental condition and others may be tired from a day's work. During most tests the motorman usually knows that he is soon to receive the stopping signal and, knowing what he is expected to do, is intent upon doing that thing in the most efficient manner. During such tests, also, the streets are usually bare of traffic and the motorman's attention is not distracted by other duties such as making up lost time, keeping a lookout to pick up passengers and obeying the conductor's signals. Usually a picked motorman is chosen, selected for his general intelligence and interest in his work. The motorman is generally in fresh physical condition and therefore in good mental condition and to that extent capable of responding to any demands made upon him. The results obtained in service at the close of a long, wearying day's work would be entirely different from the results obtained in any series of tests. It is impossible to devise any series of tests under conditions which even approximate the average conditions existing in actual service because it is impossible to tell what the average of these varying factors may be."

After much consideration the Public Service Commission, First District, New York, required cars weighing more than 25,100 lb. to be equipped with air brakes.

Weight Transfer due to Braking. The following is based on the analysis by Mr. R. A. Parke, A.I.E.E., 1902.

Retardation caused by the application of brakes to the wheels involves a redistribution of the weight which, where the retardation corresponds to the maximum brake application, results in a very serious loss of braking efficiency, unless means be provided for varying the brake-shoe pressure to correspond with the changed wheel pressures. Whatever the source of the retarding force, its operative effect in retarding the motion of the car is the same as that of an infinite number of small retarding forces each engaged in retarding the motion of an elementary portion of the mass of the car, and therefore, in order that a single retarding force, or a combination of retarding forces, shall so operate, without either changing the direction of the car's motion, or producing rotation of the structure as a whole, or calling into operation other forces to prevent such deviation or rotation, the force or the resultant of the combination of forces must be so applied that it shall pass through the center of gravity of the mass, in a direction opposite to that of the motion of the car. In utilizing the rail-friction for the retarding force, while it has the proper direction, it is applied at the lowest points of the mass of the car and must therefore either cause rotation of the entire structure or the interposition of other forces which combine with the retarding force to preserve the simple motion of translation. The car may be considered as a single mass or as being composed of three separate masses, according as it is provided with one rigid or two swiveling trucks. Rotation of the car by the eccentric retarding force does not occur in either case; but, in the first, this is because the reacting pressure of the rails upon the forward pair of wheels exceeds that upon the rear pair of wheels in such measure that the contrary rotative moment, thereby introduced, just balances that of the eccentric retarding force, also applied by the rails to the wheels. In the case of the car with two trucks, the retarding force is applied at the lower extremity of the two trucks, being equally divided between them (if constructed alike); that portion of the retarding force necessary to retard the mass of the trucks is absorbed in so doing, and the remainder is applied by the trucks to the car body at substantially its lowest extremity. In consequence, the center of gravity of the car body being above the points of application of the retarding force, rotation through the eccentrically applied retarding force is prevented only by the resisting rotative moment of a greater supporting pressure from the forward than from the rear truck. Each truck is subject to the combined rotative moment of the eccentric retarding force at its lower extremity, and the eccentric reacting force from the car body at its upper extremity, and rotation is prevented only by the contrary rotative moment of a greater supporting pressure by the rails upon the forward than upon the rear pair of wheels. Thus the very act of applying the brakes to the wheels produces a new and very different system of wheel pressures upon the rails, and it is the wheel pressures under these conditions which determine the available retarding force. As the total pressure of all the wheels upon the rails cannot vary, the existence of a greater rail pressure for the forward than for the rear pair of wheels of the truck implies the virtual transfer of a portion of the normal pressure from one pair of wheels to the other. The brake-shoe pressure upon the rear pair of wheels must be insufficient to cause the wheels to slide upon the rails and must therefore be cut down in proportion to the transfer of weight from the rear to the forward pair of wheels. But as the forward pair of wheels will become the rear pair when the car moves in the opposite direction, the brake-shoe pressure upon that pair of wheels must also be limited in the same way. Thus, the braking pressure upon each pair of wheels must be restricted to correspond with the minimum pressure of the wheels upon the rails.

External Forces Acting on Car Body in Braking. (Fig. 2.)

$$H = \frac{W_1 a}{2g}$$

$$P_2 = \frac{W_1}{2} - \frac{W_1 a j}{g l}$$

$$P_1 = \frac{W_1}{2} + \frac{W_1 a j}{g l}$$

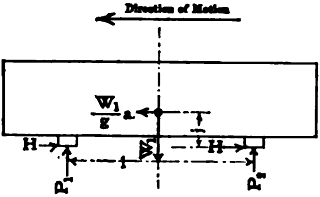


FIG. 2.—Weight transfer in braking. Car body.

in which H = horizontal retarding force on each truck center pin, pounds

P_2 = pressure between body and truck rear center plates, pounds

P_1 = pressure between body and truck forward center plates, pounds

W_1 = weight of car body, pounds. (Center of gravity being in a vertical axis midway between truck centers)

j = height of center of gravity of body above center plate surface, inches

l = distance between center pins, inches

g = acceleration due to gravity, feet per second per second = 32.2

a = rate of retardation, feet per second per second

= (miles per hour per second) × 1.467.

External Forces Acting on Rear Truck in Braking. (Fig. 3.)

$$R_2 = \frac{W_2}{2} + \frac{P_2}{2} - H\frac{h}{b} - \frac{W_2ad}{gb}$$

$$R_1 = \frac{W_2}{2} + \frac{P_2}{2} + H\frac{h}{b} + \frac{W_2ad}{gb}$$

$$T_2 = \frac{qW}{4}\left\{\frac{Wb - 2q\,(W_1h + 2W_2d)}{\left(W + 2qW_1\frac{j}{l}\right)b}\right\}$$

$$T_1 = \frac{qW}{4}\left\{\frac{Wb + 2q\,(W_1h + 2W_2d)}{\left(W + 2qW_1\frac{j}{l}\right)b}\right\}$$

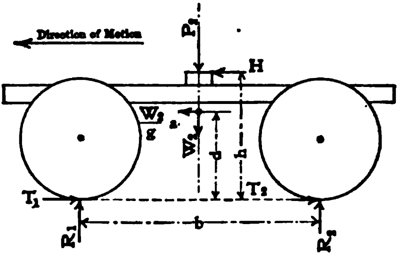


FIG. 3.—Weight transfer in braking. Truck.

in which R_2 = total pressure between rail and rear pair of wheels, pounds

R_1 = total pressure between rail and front pair of wheels of rear truck, pounds

T_2 = total maximum retarding rail friction available between rail and rear pair of wheels, pounds

T_1 = total maximum retarding rail friction available between rail and front pair of wheels of rear truck, pounds

W_2 = weight of each truck, pounds. (Center of gravity of truck being in a vertical axis midway between wheels)

W = total weight of car, pounds = $W_1 + 2W_2$

h = height of truck center plate surface above rail

b = wheel base of truck

d = height of center of gravity of truck above rail

q = coefficient of adhesion between wheel and rail (0.25 may be used for this).

For significance of other symbols see page 481.

Brake-shoe Suspension. The application of the brake-shoes at the outer face of the wheels results in an upward thrust of the brake-hangers, proportional to the brake-shoe friction, upon the rear end of the truck frame, and a corresponding downward drag upon the forward end. However, by hanging the brake-beams between the wheels, instead of outside, and inclining the hanger-links at a proper angle, the increased pressure and consequently the increased friction of the brake-shoes upon the forward pair of wheels and the diminished pressure and friction of the brake-shoes upon the rear wheels, due to the effect of the friction itself in causing the shoes to press more or less forcibly upon the wheels through the angularity of the hanger-links, are made to correspond with and compensate for the transferred weight from the rear to the forward wheels. In the same manner that running in the opposite direction causes a reversal of the conditions for the transfer of weight, so, too, the rotation of the wheels in the opposite direction causes a reversal of the effect of the inclined hanger-links, and the increased brake-shoe pressure is always applied to the wheels carrying the increased weight. The application of this method of inclined hanger-links is not without some difficulty. The chief trouble is that no constant angle of the links can be maintained, as the wearing away of the brake-shoes, together with wearing and turning down or grinding of the wheel treads, causes constant and considerable variation. Thus, if the angle of inclination and the braking pressure be calculated for the conditions existing when the brake-shoes and wheels are new, the increased angle when the shoes become much worn and the treads have been well turned off, would probably cause the forward wheels to slide upon the rails. On the other hand, if the calculations be made for turned or ground wheels and worn shoes, the rear wheels would probably slide when the wheels and brake-shoes are new. It is therefore necessary to compromise between the extremes, in reference to the angle of inclination of the hanger-links, by inclining the hanger-links at the angle determined when the brake-shoes and wheels are each half worn, and the brake-beam force must then be so established that neither pair of wheels shall be caused to slide in the extreme positions of the hanger-links.

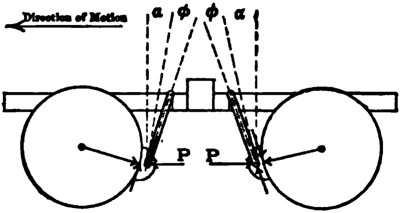


Fig. 4.—Brake-hanger suspension angles.

Angle of Suspension of Brake Hanger. (Fig. 4.) The following formula gives the angle between the brake hanger-link and the tangent to the wheel at the center of pressure of brake-shoe face necessary to secure the maximum retarding force with inside hung brake-shoes and with motors driving all axles:

$$\tan \phi = 2\,\frac{qk(W_1h + W_2d)}{rWb}$$

in which ϕ = angle between brake-shoe hanger-link and the tangent to the wheel at center of brake-shoe surface
r = coefficient of brake-shoe friction (0.33 may be used for this)

k = ratio of linear inertia to total inertia of cars. (See p. 170.)

For significance of other symbols see pages 481 and 482.

Brake-beam Pressure (*Motors Driving All Axles*). (Fig. 4.)

$$P = \frac{qW^2(1 - r^2 \tan^2 \phi) \cos \phi}{4rk\left(W + 2qW_1 \frac{j}{l}\right) \cos (\alpha + \phi)}$$

in which P = horizontal braking force applied to brake-beam in the direction of motion of the train, or, the sum of the horizontal braking forces applied to one pair of wheels in the direction of motion of the train, pounds

α = angle between radius of wheel to center of brake-shoe surface and the horizontal.

For significance of other symbols see preceding paragraph, also pages 481 and 482.

Wear on wheel and brake-shoe will bring about a change in the values of the angles α and ϕ and the dimension j, consequently the value of the force P will vary during the life of wheel and brake-shoe. The value of the force P should be determined for new wheels and brake-shoes, and again for worn wheels and brake-shoes. The lesser value thus obtained will be the maximum value of P that may be safely used.

Braking Power. The following values were given by Mr. E. H. Dewson in the Electric Journal, 1905, to show the approximate relation which the pressure applied to the brake-shoes should bear to the total weight of the braked wheels to produce a brake friction equivalent to the adhesion of the wheels to the rails. Consideration is given to the fact that the coefficient of brake-shoe friction is less at high speeds than at low.

Speed, miles per hour	Approximate ratio of total pressure on brake-shoes to total weight on braked wheels,			
	Coefficient of adhesion			
	0.30	0.25	0.20	0.15
7½	1.20	1.04	0.83	0.60
15	1.41	1.18	0.94	0.70
20	1.64	1.37	1.09	0.82
30	1.83	1.53	1.22	0.92
40	2.07	1.73	1.38	1.04
50	2.48	2.07	1.65	1.24
60	4.14	3.47	2.77	2.08

Importance of Proper Relation between Air Pressure, Piston Area and Leverage. The following is from a paper by Mr. Fred Heckler, C.E.R.A., 1907:

Pressure. If more than 2 per cent. braking power per pound of cylinder pressure is attempted, a very high braking power for light cylinder pressures is obtained and, therefore, the cars cannot be handled without shocks at low speeds and either the range between maximum and minimum braking power obtainable must be very narrow or else wheel sliding will result when the maximum power is used.

Brake Piston Area. If the ratio of cylinder piston area to cylinder pressure is excessive, it means either a low leverage, with great shoe movement or high leverage with low pressure, which gives a very narrow range between maximum and minimum braking power.

Leverage. If the leverage is too low, it means excessive air consumption and too much shoe movement; if too high (that is, brake cylinder too small for weight of car, and it is here that the principles governing brake design are violated most frequently), smooth and accurate handling of the car or train becomes impossible and the shoes are constantly grinding on the wheels, consuming energy, wearing out the shoe and causing loss of time; or else piston travel must be lengthened out, thus greatly increasing the air consumption, lengthening the time of application and release, and reducing both service and emergency braking power. Besides, the high leverage makes necessary a frequent adjustment of piston travel or a constant and very rapid decrease of braking power will result. Furthermore, high leverage, if made at truck levers, necessitates low hung brake-shoes, which, when suspended from a spring-supported part of the truck, results in great increase of piston travel and resultant decrease of braking power with the loading of the car; this always occurs at a time when readjustment of piston travel is impracticable and when instead of a decrease of braking power an increase is greatly to be desired. In addition, the danger of the levers fouling is greatly increased, particularly where the truck leverage ratio is high, and very frequent and careful inspection is required or the total loss of the brake may result.

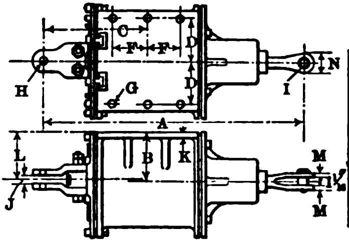
DIAMETER OF BRAKE CYLINDER, TOTAL LEVERAGE RATIO AND WEIGHT OF CAR

Diameter of cylinder in inches	Force of piston at 60 lb.	Total leverage ratio	Weight of car with brake power equal to		
			90 per cent.	100 per cent.	110 per cent.
8	3.000	12 to 1	40,000	36,000	32,750
10	4.700	11 to 1	57,800	51,700	47,300
12	6,700	10¾ to 1	80,000	72,000	65.500
14	9.200	10 to 1	102,300	92.000	83,600

Position of Brake-shoe on Wheel. If the brake-shoe is hung too far below the center of the wheel and the parts are badly worn, the application of the brakes may cause the brake-shoe to form a toggle joint with the wheel, stopping the rotation of the wheel. This makes braking inefficient and brings about unnecessary brake-shoe and wheel wear. In the above-mentioned paper by Mr. Parke it is stated that the center of the brake-shoe should be about 3½ in. below the center of the wheel. For the standard location adopted by the Central Electric Railway Association see below ("Center on Brake-shoe").

Brake Cylinder, Lever and Rigging Standards of the Central Electric Railway Association. The following recommendations of the Standardization Committee were adopted by the Association, 1911:

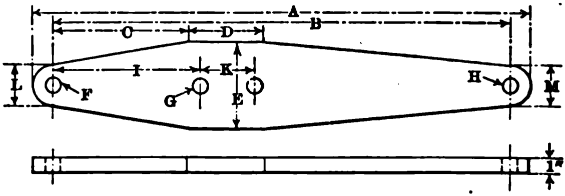
Size of Cyl.	M	N
8"x12"	5/8"	2 5/8"
10"x12"	5/8"	2 5/8"
12"x12"	5/8"	2 5/8"
14"x12"	5/8"	3"
16"x12"	5/8"	3"



Size of Cyl.	L		
	Plain Head	Emer. Valve	Triple Valve
8"x12"	4 9/16"	4 1/16"	4 1/16"
10"x12"	5 11/16"	5 3/16"	5 3/16"
12"x12"	6 3/8"	5 3/4"	6"
14"x12"	7 15/16"	7 15/16"	7 15/16"
16"x12"	9"	-	9"

STANDARD BRAKE CYLINDERS

Size of Cyl.	A			B	C			D	E	F	G	H	I	J	K
	Plain Head	Emer. Valve	Triple Valve		Plain Head	Emer. Valve	Triple Valve								
8"x12"	34 3/8"	37 5/16"	37 11/16"	4 9/16"	14 3/8"	16 13/16"	17 5/16"	4 1/16"	4 3/8"	4 3/8"	11/16"	1 3/8"	1 3/8"	1 3/8"	11/16"
10"x12"	34 3/8"	37 1/16"	36 3/4"	5 11/16"	13 3/8"	16 11/16"	15 3/8"	4 11/16"	4 3/4"	4 3/4"	11/16"	1 3/8"	1 3/8"	1 3/8"	11/16"
12"x12"	35 3/8"	38 5/8"	38 3/8"	6 3/8"	14"	16 3/8"	17"	6 3/8"	4 5/8"	4 5/8"	15/16"	1 3/8"	1 3/8"	1 3/8"	15/16"
14"x12"	35 3/8"	-	38 3/8"	7 15/16"	14 3/4"	-	17 3/4"	6 5/8"	4 5/8"	4 5/8"	15/16"	1 3/4"	1 3/4"	1 3/4"	1"
16"x12"	35 5/8"	-	38 7/16"	9"	14 5/8"	-	17 3/16"	8 5/8"	4 5/8"	4 5/8"	1 1/16"	1 3/4"	1 3/4"	1 3/4"	5/8"



CYLINDER LEVERS

Size of Cyl.	A	B	C	D	E	F	G	H	I	K	L	M
8"x 12"	29"	26"	6 1/4"	8 1/4"	3 3/8"	1 3/8"	1 3/8"	1 3/8"	7 3/4"	5 1/4"	3"	3"
10"x 12"	31"	28"	7 1/4"	8 1/4"	4 3/8"	1 3/8"	1 3/8"	1 3/8"	8 3/4"	5 1/4"	3"	3"
12"x 12"	34 3/8"	31 3/8"	8 9/16"	8 11/16"	6"	1 3/8"	1 3/8"	1 3/8"	10 1/16"	5 11/16"	3"	3"
14"x 12"	39 5/16"	35"	9 3/8"	9 3/8"	7"	1 3/4"	1 3/8"	1 3/8"	11"	6 3/8"	3 3/8"	3"
16"x 12"	39 5/16"	36"	10"	9 3/8"	8 3/8"	1 3/4"	1 3/8"	1 3/8"	11 3/8"	6 3/8"	3 3/8"	3"

ALL PINS TO BE 1/32" LESS IN DIAMETER THAN DRILLED HOLES.

FIG. 5.—Cent. Elec. Ry. Assn. standard brake cylinders and levers.

(*A*) *Revision of Standard Air Brake Cylinders, Levers and Brake Rigging.* Recommended: That the standard air brake practice should be according to revised print No. C-2 (see Fig. 5) as follows:

1. All braking power to be based on 50 lb. cylinder pressure.

This in order to avoid confusion when stating percentages of braking power that may be figured on different brake cylinder pressures; *e.g.*, 100 per cent. braking power on 60 lb. cylinder pressure may be taken to mean greater than 100 per cent. on 50 lb. cylinder pressure, and if this is always referred to on a common base, confusion will be avoided.

2. All interurban cars to be braked at 100 per cent. of light weight on rails and motor axles, and 90 per cent. on non-motor and trailer axles.

3. All city cars to be braked at 85 per cent. on motor axles and 75 per cent. on non-motor and trailer axles. Seventy-five per cent. on 50 lb. is practically the same as 90 per cent. on 60 lb.

4. Brake pressure to be 70 lb. per square inch with automatic equipments.

5. Governor adjustment—85 and 100 lb. for automatic equipment. Governor adjustment—50 and 65 lb. for straight air equipment.

6. The standing piston travel adjustment—4 in.

7. Total truck leverage to be 6 to 1 for long wheel base trucks for inside hung motors, and 9 to 1 for short wheel base trucks with outside hung motors.

8. A 12 to 1 maximum total leverage is permissible when brake-shoes are hung not more than 2 in. below the center of the wheel. If brake-shoes are hung lower than this it will be necessary to reduce the maximum total leverage accordingly, and if brake-shoes should be hung 5 or 6 in. below the center of the wheel a total leverage of 10 to 1 should be the limit.

9. The standard M.C.B. recommendations for maximum stress in levers, rods and pins to be adopted as follows: (*a*) Maximum stress in levers—23,000 lb. per square inch. (*b*) Maximum stress in rods, except jaws—15,000 lb. per square inch, no rod to be less than ⅞ in. (*c*) Maximum stress in jaws to be 10,000 lb. per square inch. (*d*) Maximum shear on pins—10,000 lb. per square inch, single shear. (*e*) Diameter of pins to provide a bearing value not to exceed 23,000 lb. per square inch, projected area.

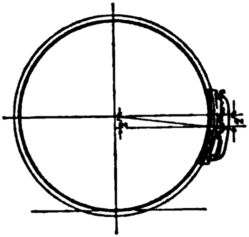


FIG. 6.—Standard brake-shoe position, Cent. Elec. Ry. Assn.

10. Safety valve adjustments—10 lb. above maximum governor setting.

(*B*) *Center on Brake-shoe.* Recommended: That center of brake-shoe be set 2 in. below center of wheel. (See Fig. 6.)

Clasp Brake. The following is based upon comments by Mr. S. W. Dudley, A.S.M.E., 1914, after the Pennsylvania-Westinghouse 1913 tests: The use of the clasp type of brake rigging eliminates unbalanced braking forces on the wheels and so avoids the undesirable and troublesome journal and truck reactions that come from the use of heavy braking pressures on but one side of the wheel. This not only has an important effect on freedom from journal troubles, but it also enables the wheel to follow freely vertical inequalities of the track. Although the clasp brake rigging will produce better stops than a single shoe brake rigging equally well designed (other conditions being equal), its advantage in this direction is of less importance than in the improved truck, journal and shoe conditions. The use of two shoes per wheel permits a design of rigging which will allow flanged shoes to be used without danger of pinching flanges and causing excessive flange wear or non-uniform brake forces which result when flanged shoes are used with rigid beam connections. The use of two shoes instead of one per wheel will result in a higher coefficient of friction and less wear per unit of work done. A comparison of the values of mean coefficient of friction for standard and for clasp brake conditions indicates a decided advantage for the clasp brake throughout the entire range of braking powers. The gain in favor of the clasp brake with slotted shoes amounts to about 40 per cent. at a braking power of 180 per cent., and 100 per cent. at a braking power of 40 per cent., an average gain for the whole range of braking powers of about 70 per cent.

From a brake-shoe standpoint the advantage of using two shoes instead of one shoe per wheel may be summed up as follows: First, the clasp brake is associated with but one-half the wheel load and consequently has but one-half as much energy to absorb; second, the clasp brake-shoe is working at only one-half the shoe pressure at which the standard shoe must work under the same braking power; third, the available work area for the same amount of energy to be absorbed is double.

A possible source of disadvantage when using two shoes per wheel is that a warped or poorly bearing shoe is subjected to less pressure tending to force it into a good contact with the wheel. For this reason, though the available shoe area is doubled when using clasp brakes, the actual amount of working metal throughout the stop may be less than with a single shoe, which is less capable of resisting the tendency of the heavier pressure to cause a better fit of shoe to wheel.

With plain solid shoes the durability will be increased 41.1 per cent. under clasp brake conditions as compared with that under single shoe conditions. With plain slotted shoes the durability will be increased 33.5 per cent. under clasp brake conditions as compared with that under single shoe conditions.

Following is a description of the clasp brake installation on the cars of the New York, Westchester and Boston Railway: Each motor truck is fitted with eight brake-shoes, two shoes being applied to each wheel. The purpose of this clasp brake design is to reduce the pressure per brake-shoe to reasonable limits when an emergency application of the air brake is made. It also minimizes the heating effect on the brake-shoes, as the regular schedule in which these cars are used involves frequent station stops from high speeds. A short brake rod with a clevis and roller connects the cylinder lever to a radius bar. The latter is supported at each end by rocking levers which tend to move by gravity into a position to release the brake-shoes when the pull from the air brake cylinder is released.

From each end of the radius bar a rod extends toward the transoms and is attached in the center of a short horizontal floating lever. The inner end of this lever is fastened to the top of a live brake lever, carrying a shoe bearing on the inside of one wheel. A pair of rods straddling the wheel connect the bottom of this live lever to the bottom of the dead lever which is hung from the truck end frame.

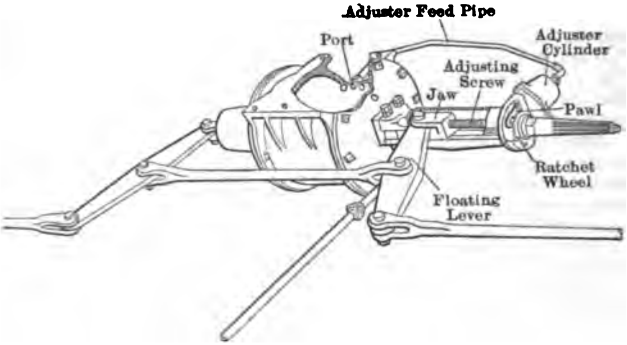


FIG. 7.—American automatic slack adjuster.

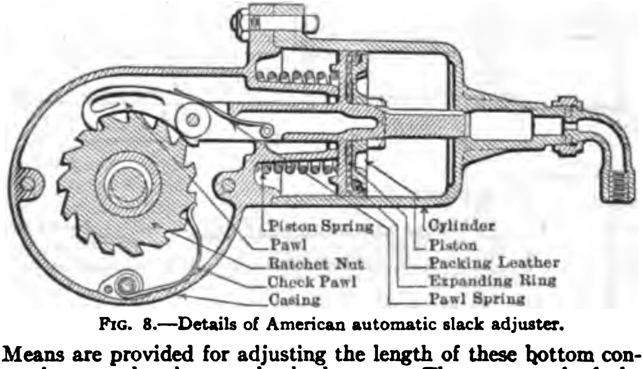


FIG. 8.—Details of American automatic slack adjuster.

Means are provided for adjusting the length of these bottom connections as the shoes and wheels wear. The outer end of the horizontal floating lever is connected by a rod to the end of a centrally pivoted lever of the same length on the other side of the bolster. The inner end of this pivoted lever is fastened to the live brake lever of the other wheel. The arrangement of levers on each side of the truck is the same, but the two sides operate independently of each other except for the single connection through the radius bar.

Automatic Slack Adjuster. The function of the automatic slack adjuster is to automatically maintain the brake-shoe travel at a practicable minimum while keeping the piston travel at a minimum and nearly uniform. By doing this, a maximum efficiency of brakes is approached, the necessity of inspection for the adjustment of brakes is eliminated, the brakes on all cars operate as nearly alike as may be and their operation is nearly the same throughout the life of the brake-shoes, the energy consumption and brake-shoe wear due to shoes dragging are eliminated and a minimum of air and the accompanying minimum amount of energy and compressor duty are demanded. Automatic slack adjusters are usually located either at the brake cylinder or on the truck. Figs. 7, 8 and 9 show typical adjusters located at the brake cylinder and Fig. 10 shows a typical adjuster located on the truck where it takes the place of the ordinary turnbuckle brake rod connecting the bottoms of the live and dead levers.

American Automatic Slack Adjuster. (Figs. 7 and 8.) The adjuster cylinder is connected by the adjuster feed pipe to a port in the brake cylinder wall. When the brake piston uncovers this port, compressed air flows to the adjuster cylinder (see Fig. 8), thus operating its piston which in turn actuates a pawl engaging the ratchet wheel and nut on the screw. Release of brakes allows the spring in the adjuster cylinder to return the piston in the latter to its normal position, resulting in the rotation of the ratchet nut on the adjusting screw. The inner end of the screw carries a jaw

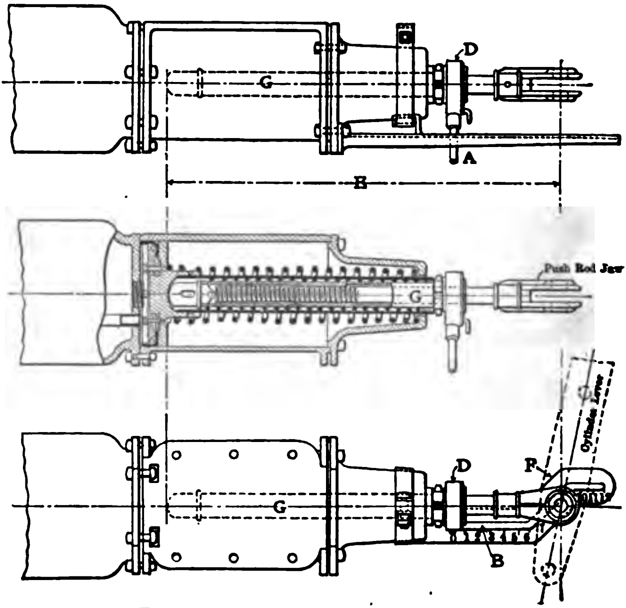


FIG. 9.—Creco automatic slack adjuster.

which acts as a fulcrum for the adjustable or floating lever of the brake cylinder.

Creco Automatic Slack Adjuster. (Fig. 9.) Pin *A* traveling in slot *B* of bracket *F* passes beyond the straight line which is made the length of the desired piston travel and goes into that part of the bracket slot which is at an angle of 45 deg. from the straight line or the line of normal piston travel. The action of the pin in traveling through the angled portion of the slot is to carry the ratchet pawl over the teeth of the ratchet *D*, and upon the return of the pin back to the angle with the release of the brakes to turn the barrel *C*, which is rigidly attached to the ratchet, upon the screw portion of the push rod proper, thereby lengthening the distance *E* from the lever pin hole in the jaw to the end of cylinder *G*.

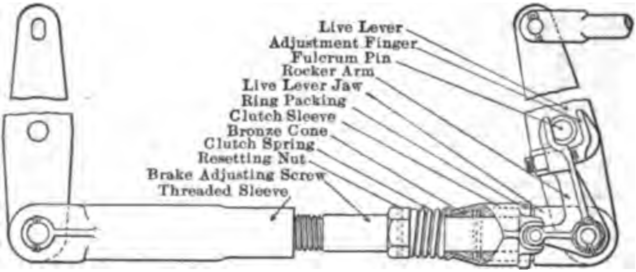
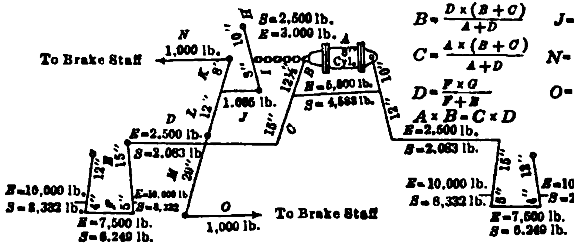


FIG. 10.—Anderson automatic slack adjuster.

Brake Rigging Calculation. Fig. 11 gives formulas for calculating truck pull rod force, brake-shoe pressure and the dimensions of the lever carrying the brake-shoe for the three general methods of suspension. (See also Fig. 15.) Figs. 12 and 13 give formulas which show the relations between the brake-shoe pressures on adjacent wheels and the pull rod force By an adjustment of the lever dimensions these brake-shoe pressures may be made to bear a desired relation to each other.

The following example of brake rigging calculation (see Fig. 15) is by Mr. E. H. Dewson, Electric Journal, 1905:

A car weighing 46,700 lb. without load has a weight of 32,200 lb. on the motor truck and 14,500 lb. on the trailer truck. The motor truck is equipped with inside hung brake-shoes connected directly to a double set of levers, no brake-beams being used. The trailer truck has outside hung shoes mounted on brake-beams, consequently a single set of levers is used. One hundred per cent. brake power on the motor wheels requires a force of 8050 lb. at each brake-shoe. Ninety per cent. brake power on the trailer truck requires a force of 6525 lb. at each brake-beam. The total brake power will be 45,250 lb., and as a 10-in. piston under a pressure of 60 lb. per square inch exerts a force of 4700 lb., the total leverage ratio will be about 9.6 to 1, which is satisfactory. The levers supplied with the motor truck are 27 in. long and the shoes are hung



$$B=\frac{D\times(B+C)}{A+D}\qquad J=\frac{A\times H}{H+I}$$

$$C=\frac{A\times(B+C)}{A+D}\qquad N=\frac{J\times L}{K+L}$$

$$D=\frac{F\times G}{F+E}\qquad O=\frac{J\times L}{M}$$

$$A\times B=C\times D$$

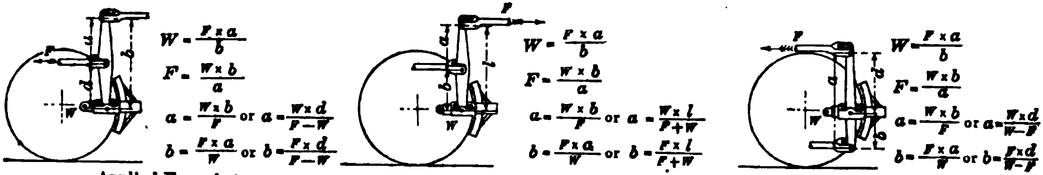
Light Weight of Motor Car, 40,000 lb.
Braking Power, 40,000 lb. or 100 Per-cent
E indicates Forces in Emergency Applications and
S indicates Forces in Full Service Applications.

The following table gives the forces exerted upon the pistons of the different size cylinders with pressures of 50 lb., 60 lb. and 70 per sq. in.

Size of Cylinder	16"	14"	12"	10"	8"	7"
Area of Cylinders				78,54 sq.in.,	50,27 sq.in.,	38,48 sq.in.
50 lb. Pressure	10,050	7,700	5,650	4,000	2,500	1,950
60 lb. Pressure	12,050	9,200	6,700	4,700	3,000	2,300
70 lb. Pressure	14,100	11,800	7,900	5,500	3,500	2,700

AUXILIARY RESERVOIRS USED WITH DIFFERENT SIZES OF BRAKE CYLINDERS.

10"x 33" Auxiliary Reservoirs with 8" Brake Cylinder of all kinds
12"x 33" " " " 10" " " " " "
14"x 33" " " " 12" " " " " "
16"x 33" " " " 14" " " " " "
16"x 42" " " " 16" " " " " "



$$W=\frac{F\times a}{b}\qquad F=\frac{W\times b}{a}\qquad a=\frac{W\times b}{F}\text{ or }a=\frac{W\times d}{F-W}\qquad b=\frac{F\times a}{W}\text{ or }b=\frac{F\times d}{F-W}$$

Applied Force between Fulcrum and Delivered Force.

$$W=\frac{F\times a}{b}\qquad F=\frac{W\times b}{a}\qquad a=\frac{W\times b}{F}\text{ or }a=\frac{W\times l}{F+W}\qquad b=\frac{F\times a}{W}\text{ or }b=\frac{F\times l}{F+W}$$

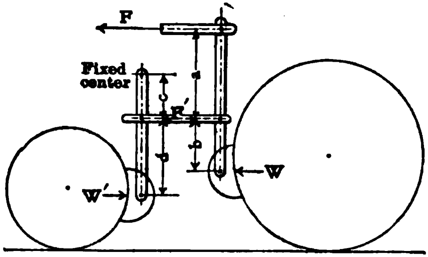
Fulcrum between Applied and Delivered Forces.

$$W=\frac{F\times a}{b}\qquad F=\frac{W\times b}{a}\qquad a=\frac{W\times b}{F}\text{ or }a=\frac{W\times d}{W-F}\qquad b=\frac{F\times a}{W}\text{ or }b=\frac{F\times d}{W-F}$$

Delivered Forces between Fulcrum and Applied Force.

FIG. 11.—Formulas for calculating brake rigging (Hartford Shop Instruction Print).

7¼ in. from the lower end. Considering the dead lever first with its fulcrum at the upper end we know the delivered force W and its distance b from the fulcrum, also the distance a from the fulcrum to the applied force F; substituting these values in the equation $F = \frac{W \times b}{a}$ we have $F = \frac{8050 \times 19.5}{27} = 5814$ lb. as the stress in the adjusting rod. Considering the lower end of live lever as the fulcrum we have $W = 8050$ lb., $b = 7.5$ in. and $a = 27$ in., consequently the pull at the upper end $F = \frac{8050 \times 7.5}{27} = 2236$. The proof is that $5814 + 2236 = 8050$. As a pull of 2236 lb. must be exerted on each side of the trucks, the stress in the truck pull rod will be 4472 lb. For the dead lever of the trailer truck we have $W = 6525$ lb., $b = 22.5$ in. and $a = 15$ in., consequently the stress in the adjusting rod is $F = \frac{6525 \times 22.5}{15} = 9787.5$ lb. With the intermediate point of the live lever taken for the fulcrum, $W = 6525$ lb., $b = 7.5$ in. and $a = 15$ in. and the stress in the pull rod $F = \frac{6525 \times 7.5}{15} = 3262.5$ lb. The proof is that $6525 + 3262.5 = 9787.5$.



$$W = \frac{F \times a}{b} \qquad F = \frac{W \times b}{a}$$

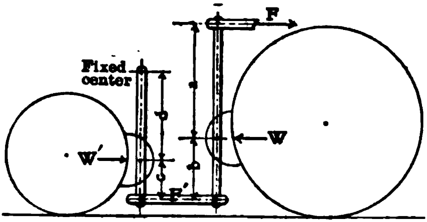
$$a = \frac{w \times b}{F} \qquad b = \frac{F \times a}{w}$$

$$W' = \frac{F\,(a + b)\,c}{(c + d)\,b} \qquad W' = \frac{F' \times c}{(c + d)}$$

$$F' = \frac{F\,(a + b)}{b} \qquad W = W' \text{ when } \frac{a}{b} = \frac{c}{d}$$

See also Fig. 9.

FIG. 12.—Braking pressures on adjacent pairs of wheels, I.



$$W = \frac{F\,(a + b)}{b} \qquad F' = \frac{F \times a}{b}$$

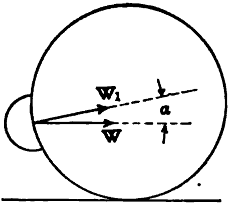
$$F = \frac{W \times b}{(a + b)} \qquad W' = \frac{F'\,(c + d)}{d}$$

$$a = \frac{(W - F)b}{F} \qquad W' = \frac{F\,(c + d)\,a}{b \times d}$$

$$b = \frac{F \times a}{W - F} \qquad W = W' \text{ when } \frac{a}{b} = \frac{d}{c}$$

FIG. 13.—Braking forces on adjacent pairs of wheels, II.

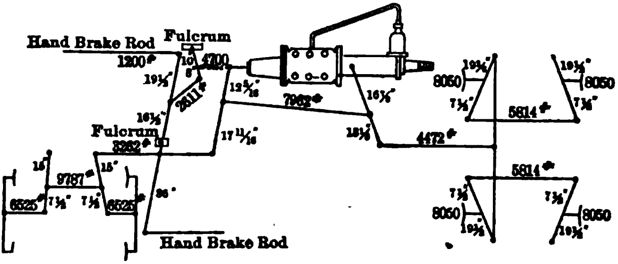
It is now necessary to so proportion the push rod lever that with a piston force of 4700 lb. it will deliver 3262 lb. (neglecting the half) to the trailer truck pull rod, and the cylinder lever that it will deliver 4472 lb. to the motor truck pull rod. For efficient operation of the slack adjuster these levers should not be less than 30 in. long; with short levers the action of the adjuster would cause excessive angular distortion. If the applied force at the cylinder end of the push rod lever is 4700 lb., and the delivered force at the pull rod is 3,262 lb., that at the push rod will be 4700 + 3262 = 7962 lb. Assuming that the pull rod pin is the fulcrum we have $F = 4700$, $a = 30$ in., $W = 7962$ and $b = \frac{F \times a}{W} = \frac{4700 \times 30}{7962} = 17\frac{11}{16}$ in. For the cylinder lever we have $F = 7962$ lb., $W = 4472$ lb., and $b = 30$ in., therefore $a = \frac{4472 \times 30}{7962} = 16\frac{7}{8}$ in.



$W_1 = w \cos \alpha$ in which W_1 is force normal to the wheel treads at center of brake-shoe surface.

FIG. 14.—Relation between horizontal and normal braking forces.

With the ordinary brake handle, staff and chain supplied with electric cars, 1200 lb. is about as much force as the average man can exert on the hand brake pull rod. This must be multiplied to 4700 to give the same brake power by hand as by air pressure. Using a multiplying lever 18 in. long and connecting to the push rod pin by a chain fastened 10 in. from the fulcrum, the force required at the end of the lever will be $\frac{10 \times 4700}{18} = 2611$ lb. Assuming that the hand brake lever is 6 ft. long and pivoted at the center, we have $F = 1200$ lb., $a = 36$ in., $W = 2611$ lb. and $b = \frac{1200 \times 36}{2611} = 16.54$ in., or practically 16½ in.



Car weighs 46,700 lb.
32,200 lb. on motor truck 100% brake power on motor truck
14,500 lb. on trailer truck 90% brake power on trailer truck

FIG. 15.—Calculations for a specific brake equipment.

Brake Rigging Efficiency. A part of the brake cylinder force is lost in being transmitted to the brake-shoe and as the leverage of the brake rigging is calculated from the piston force it is necessary to make proper allowance for this frictional loss. The efficiency of the rigging will depend upon the equipment, condition and pressure used. Tests to determine its value have been unsatisfactory. Such tests have yielded various values, but they indicate that in most cases the value for ordinary equipment in good condition probably lies between 80 and 85 per cent. Commenting on the Pennsylvania-Westinghouse 1913 tests, Mr. S. W. Dudley, A.S.M.E., 1914, states that they indicate that at least 85 per cent. transmission efficiency could be obtained with either single shoe or clasp brake rigging. These tests indicate that the following features are important in securing the maximum overall brake rigging efficiency: (*a*) protection against accidents that may result from parts of rigging dropping on the track; (*b*) maximum efficiency of brake rigging at all times to insure the desired stopping with a minimum per cent. of braking power; (*c*) uniform distribution of brake force, in relation to weight braked, on all wheels; (*d*) with a given nominal per cent. braking power, the actual braking power to remain constant throughout the life of the brake-shoes and wheels; (*e*) piston travel to be as near constant as practicable under all conditions of cylinder pressure; (*f*) minimum expense of maintenance and running repairs of brake rigging between the stopping of cars.

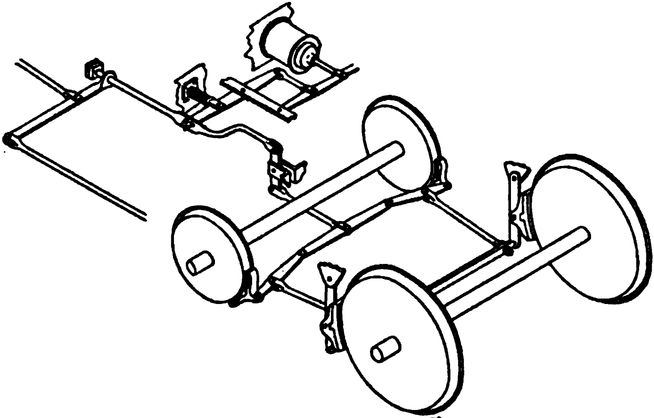
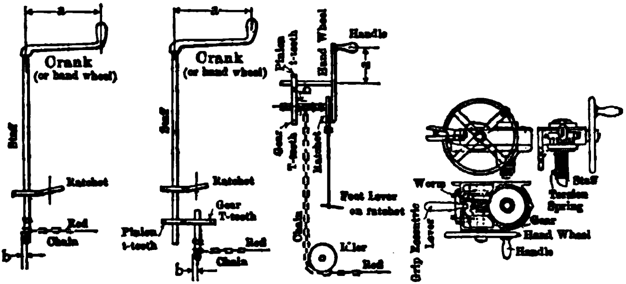


FIG. 16.—Brake rigging for low floor car.

Brake Rigging for Low Floor Car. Fig. 16 shows the general scheme of the foundation brake gear used on the New York low floor cars. Levers pivoted to the truck at their upper end serve as hangers for the brake-shoes for the motor wheels. The lower ends of these levers are connected by a tie bar actuated by two compression members, which at their other ends form fulcrums for two horizontal levers. The short ends of the horizontal levers apply pressure to the shoes of the pony wheels. The long ends are connected by an equalizing bar which is acted on by a push rod, the latter being pinned to the lower end of a vertical lever fulcrumed to the car body. Thus the brake rigging of the truck clears the low-hanging body and divides the braking power between the wheels in proportion to the weight carried, due allowance having been made for the inertia of the revolving parts. Provision for adjusting the brake rigging to compensate for shoe wear has been made in the construction of the compression members between the brake-beam of the motor wheels and the small horizontal levers. The brake-beam end of these compression members is threaded and passes through holes in the beam; sleeve nuts, of which the sleeves fill the hole in the beam nicely, provide the means for making the adjustment, after which the sleeve nuts are locked together so that there is no lost motion between the beam and the compression members. The upper end of the vertical lever above mentioned is connected to the pull rod proper of the car-body brake rigging, which is actuated through a pair of levers by a brake cylinder 7 in. in diameter and of 8-in. stroke. Space limitations necessitate the use of a double system of levers together with the shortest possible brake cylinder. Truck pull rods extend beyond the cylinder lever in order that the hand brake connection may be made through a pair of equalizing levers. The pull rod end of each of these levers is provided with an eye so that the pull rod is free to move through it, when actuated by the brake cylinder, without disturbing the hand brake. This rod was necessary because the very small clearance between the under side of the car flooring and the surface of the street would not admit of any sagging chains such as are used ordinarily for the connection between the hand brake rigging and the portion operated by air. The release of the brake-shoes is accomplished by the weight of the shoes on the motor wheels and a release spring on the car body which acts against one of the cylinder levers. (See also page 508).

Typical Hand Brake Schemes. The more common hand brakes may be divided into four types, namely: gearless staff, spur-geared staff, spur-geared staffless and worm-geared staff. The scheme of each of these is shown by Fig. 17. Although the drum on which the chain is wound may be of uniform diameter throughout its length, many of the drums now used are conical or eccentric so that the slack chain may be rapidly taken up over the portion of large radius and the final tension applied to the chain at small radius, thereby giving a maximum tension when it is needed. As the crank or handwheel is turned, the tension is transmitted through this chain, thence through a rod, thence through a chain to the brake lever system (see Fig. 15). In calculating the relation of tension in the hand brake rod to the pull applied to the crank, the distance *b*, Fig. 17, is the effective radius of the drum when the brakes are fully applied. This distance varies according to the shape of the chain, its method of winding and the travel of the brake-shoes. Tests made by Mr. G. L. Fowler on the cars of the Brooklyn Heights Company, using dynamometers in the truck pull rods, showed the braking pressure at the wheels to vary as much as 40 per cent. with a given pressure applied to the brake handle on different applications on the same car. This was found to be due entirely to the manner in which the chain rolled on the brake staff.



A-Gearless Staff

B-Spur Geared Staff

C-Spur Geared Staffless

D-Worm Geared Staff

FIG. 17.—Typical hand brake schemes.

Gearless Staff Hand Brake (A, Fig. 17). The gearless staff is the most common type of hand brake used on light cars.

$$(\text{tension in rod}) = \frac{a}{b} \times (\text{pull on handle}).$$

Spur-geared Staff Hand Brake (B, Fig. 17). An increase in mechanical advantage over that of the gearless staff type is secured by the spur gear.

$$(\text{tension in rod}) = \frac{a}{b} \times \frac{T}{t} \times (\text{pull on handle}).$$

Spur-geared Staffless (C, Fig. 17). The force applied at the handwheel is transmitted through a spur gear to the winding drum. The ratchet is normally held at release by gravity and is set by a foot lever. Most satisfactory results have been secured with gear ratios of 14 : 34 and 12:36.

$$(\text{tension in rod}) = \frac{a}{b} \times \frac{T}{t} \times (\text{pull on handle}).$$

Worm-geared Staff (D, Fig. 17). A worm on the handwheel shaft drives a gear on the staff. Ordinarily a compression spring holds the worm in mesh with the gear. Release is obtained by means of a grip eccentric lever which disengages the worm from the gear. The slack chain is taken up by a torsion spring.

Hand Brake Maintenance (see also Page 512). Brake-staff defects are due principally to the staff binding and not releasing freely, and are often caused by the drawbar rest being displaced. Brake-chain troubles are largely due to the hand brake binding and jamming between the brake staff and sill. One of the most important points in the transmission of braking power from the brake handle to the wheels is the winding of the brake chain on the staff. A close link chain should be used and care taken to have sufficient lead to the chain to allow it to roll on the staff without one turn binding or running upon another. There should also be sufficient release spring pressure to pull slack chain promptly from the staff, so that the chain will wind on the staff directly below the eye bolt. Great care should also be taken to see that the lead of the chain is such as to prevent its winding above the eye bolt and jamming against the platform and rendering the brakes inoperative. Another point to be guarded against is that of the chain at the rear end of the car catching on the snow scrapers and thus preventing an application of brakes. Inspection of the brake chain should guard against badly worn links, or eye bolts, or the possibility of nuts working off the eye bolts.

Types of Air Brakes. Straight air brake system, recommended for single-car operation only.

Emergency straight-air system, suitable for two car operation, particularly when one is operated single most of the time and with a trailer added during rush hours.

Automatic air brake system, suitable for trains of three or more cars.

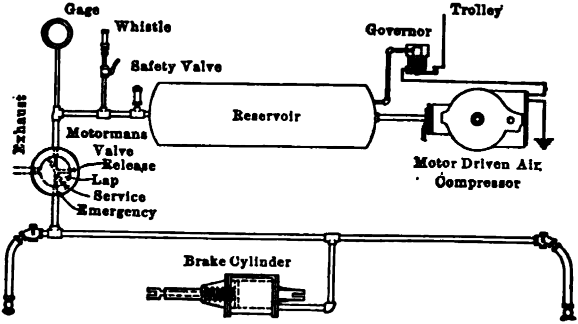


FIG. 18.—Straight air brake system.

Combined straight and automatic air brake system, for locomotive service and for operation of single cars or trains of several cars.

Electropneumatic air brake system, for service similar to that of the automatic system.

Straight Air Brake System. (Fig. 18) The straight air-brake system consists essentially of a source of compressed air (either a tank filled at intervals from an air compressor, motor or axle driven, located upon the car, or sometimes from a compressor at charging stations); a reservoir which receives the air from the compressor or charging tanks and in which the pressure is maintained practically constant by means of a reducing valve, or by a governor which automatically controls the operation of the compressor; a brake cylinder, the piston of which is connected to a system of brake levers in such a manner that when the piston is forced outward by air pressure the brakes are applied; an operating valve mounted in each vestibule by means of which the compressed air is either admitted to or released from the brake cylinders; a pipe system connecting the above parts, including cut-out valves, hose, and angle fittings between cars. In order to prevent any possibility of accumulating an excessive pressure, a safety valve designed to open at 100 lb. per square inch is placed in the air supply system. A set of pressure gages is usually supplied with each complete equipment in order that the motorman may observe the pressure in the reservoir and remedy any defects in the governing apparatus.

To operate the motorman's valve the handle is inserted when the valve is in lap position where the slot in the body of the valve is enlarged for this purpose (and to prevent its removal in any other position). In this position the valve is set so that air can neither pass into nor out of the brake cylinder. Moving the handle to the left places the valve in full release, that is, connects the brake cylinder to the atmosphere and allows the air which holds the brakes applied to escape, when the spring which is opposed to the air pressure restores the piston and releases the brakes. To partially release the brakes, which is necessary in braking in order to prevent shocks as the car stops, the handle is moved to the left and returned to lap position. This reduces the pressure on the brake-shoes, but does not entirely release them. To apply the brakes for a service stop, the handle is moved to the right a little past the lap position, then back to lap. This connects the reservoir with the brake cylinder through a small opening in the valve, then holds the pressure constant until it is necessary to release or apply more pressure. Moving the handle further to the right connects the reservoir to the brake cylinder through a large opening, thus causing the cylinder to fill rapidly and quickly apply the brakes with maximum pressure. Sand is usually applied to the tracks as soon as the handle is turned to emergency to avoid skidding the wheels. In descending grades a light application of the brakes may be made and the handle returned to lap. A sufficient length of time should be allowed for car to feel the effect of the brakes before applying more pressure. If speed is higher than desired a second light application should be made and operation repeated as often as necessary until the desired speed is obtained, or until the car has left the grade.

The straight air system of air brakes, although only recommended for single-car operation, may be used when operating with a trailer. The equipment for trail cars consists of a brake cylinder and system of levers similar to the ones on the motor car, a length of pipe running the entire length of the car and provided with hose couplings and cut-out cocks for connections to the forward and rear cars. In connecting up trail cars, all the hose couplings must be thoroughly united to insure that air will apply throughout the entire train. All the cut-out cocks must be opened except those on the rear of the last car, and the front of the first car, which must be closed.

So far as single-car operation is concerned, the straight air brake system is very satisfactory, as the desired flexibility in the matter of graduations of applications and release of the brakes with due regard to the passengers standing can readily be secured, and this apparatus is usually so simple in construction that the motorman may become familiar with its operation to such an extent that accurate stops may be secured with a minimum amount of instruction. In trains of considerable length, however, the response of the brakes on the rear cars is too slow, since all the air must pass from the main reservoir on the front car through the opening in the motorman's valve to the brake cylinders of each car. As the addition of each car adds to the volume of the brake system, the main reservoir on the first car must be considerably increased in order that the pressure will not be reduced to such an extent that the brake application will not be sufficient and result in overrunning the desired stopping place. These latter objections would not be sufficient to prevent the use of this type of air brakes on short trains of two or three cars were it not for the fact that a broken hose connection or leaky train pipe renders the brakes on the whole train inoperative.

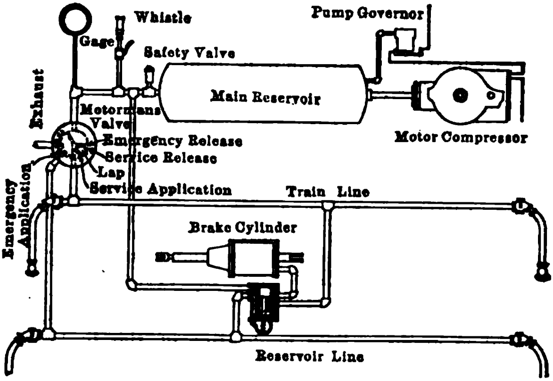


FIG. 19.—Emergency straight air brake system.

Emergency Straight Air Brake System. (Figs. 19 and 20.) The emergency straight air brake differs from the straight air brake in the details of the motorman's valve and in the addition of an emergency valve and reservoir line which connects the motorman's valve with the emergency valves. In the case of a trail car an auxiliary reservoir is also added as shown in Fig. 21.

In the ordinary operation of single cars or short trains, the emergency valve is seldom brought into play. It is necessary, however, to provide a short direct passage from the reservoir to the brake cylinder in order to ensure the quickest possible action in time of emergency and to provide some means of automatically braking the rear cars should a break occur in the train line. At other times when it is desired to make a service application or release, the air is admitted or exhausted through the motorman's valve the same as in the straight air brake.

With the motorman's valve in the emergency position, it allows air to escape from the reservoir line and causes the reservoir pressure, which is above that in the emergency valve, to compress the spring which holds it in its normal position, thus opening a port in the casing of the valve to the brake cylinder for the direct passage of the reservoir air. At the same time all communication with the train and reservoir lines is cut off. To release the brakes, therefore, it is necessary to first return the emergency valve to its normal position by recharging the reservoir line to the reservoir pressure, which allows the spring under the valve to return it to its original position, then brakes can be released the same as after a service application by exhausting the air from the train line. The recharging of the reservoir line is accomplished by moving the motorman's valve to emergency release position at the extreme left of the slot in the body of the valve where a connection is made between the main reservoir and the reservoir line as well as one between the train line and atmosphere. With the emergency valve in normal position there is a direct passage to the train line and brake cylinder, and the service applications and release are made by increasing or decreasing the pressure in the train pipe.

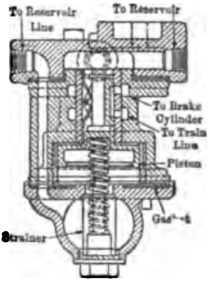


FIG. 20.—Straight air brake emergency valve.

Emergency Straight Air Brake System for Trail Car. (Fig. 21.) In the case of a trail car the auxiliary reservoir is charged during emergency release by the air pressure equalizing on both sides of the slide valve through the charging grooves in the valve casing. At other times it is charged from the main reservoir through the charging grooves in the emergency valve on the motor car.

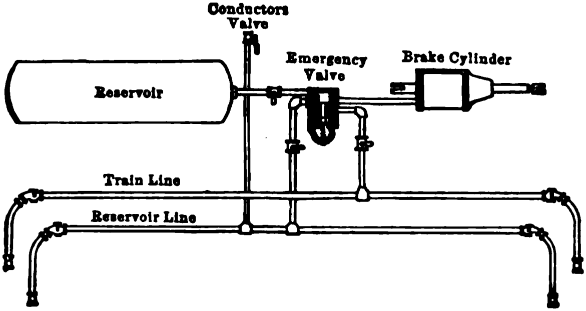


FIG. 21.—Emergency straight air brake for trail car.

In case of accident to the reservoir line the air can be exhausted from the auxiliary reservoir and the train operated on straight air without interrupting the service. An accident to the train line has no effect upon the action of the emergency valve which still can be operated as ordinarily by throwing the motorman's valve to the emergency position. As this system has the straight air brake principle most prominent it is subject to the same objections which prevent the use of the straight air brake on longer trains, namely, the time element. For this reason, the automatic air brake is used generally on trains of three or more cars.

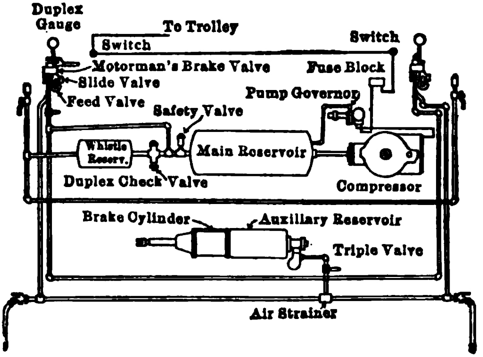


FIG. 22.—Automatic air brake system.

Automatic Air Brake System. (Fig. 22.) The automatic air brake differs from the straight air brake in that the former requires a decrease in the train-pipe pressure to apply the brakes, and an increase in pressure to release them, whereas in the latter, air is admitted to the train pipe to apply the brakes and exhausted to release them.

The apparatus required for this system in addition to that already mentioned for the straight air brakes is as follows: A set of duplex pressure gages which indicate simultaneously the pressure in the main reservoir and in the train pipe; an auxiliary reservoir for storing the air used by each car in braking; a triple valve, the function of which is to admit air from the auxiliary reservoir into the brake cylinder and to release it therefrom (in release position, the auxiliary reservoir is recharged), and an air-whistle reservoir with suitable check valve for supplying air to the air whistle.

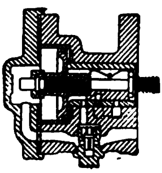


FIG. 23.—Plain triple valve.

This system is capable of a great many refinements which may be added or omitted as requirements of a particular service may prescribe. The main points of difference between particular automatic air brake equipments will generally be found in the details of the triple valves, and the addition of pressure maintaining and reducing valves, which are essential in certain classes of grade work in order to prevent brakes leaking off. These particulars have been intentionally omitted from this consideration to avoid undue complexity. Two forms of triple valves, however, need to be considered here inasmuch as the plain triple valve, Fig. 23, is only used on comparatively short trains, about five cars in length, whereas the quick action triple valve, Fig. 24, is designed to be used on much longer trains.

For the emergency position shown in diagram, Fig. 24, the train line is open to the atmosphere, allowing auxiliary reservoir pressure on the right of the slide-valve piston to force it to the left against the graduating spring, compressing it and uncovering the brake cylinder port, thus permitting air to flow from the auxiliary reservoir directly into the brake cylinder, at the same time the ports leading to the atmosphere and to the train pipe are closed.

To release the brakes, the main reservoir air is admitted through the train to the chamber at the left of the slide-valve piston, forcing it to the right and connecting the brake cylinder port to the exhaust port, at the same time air at the main reservoir pressure raises the check valve and recharges the auxiliary reservoir to main reservoir pressure.

A graduated release of the brakes may be obtained with this type of valve by piping the exhaust from the triple valve to the motorman's valve where a movement of the valve handle will release the air the same as is in the straight air brake.

A service application requires only a slight reduction in train-line pressure (from 5 to 7 lb.) which is sufficient to permit the slide-valve piston to slightly compress the graduating spring and partially open the brake cylinder port. When the auxiliary reservoir pressure has been reduced to about the same as the train-line pressure, the graduating spring will return the slide valve to lap position, closing all the ports before the brakes are fully applied. The auxiliary reservoir and brake cylinder are usually so proportioned that the brakes are fully applied when the brake piston displacement is sufficient to reduce the auxiliary reservoir pressure about 15 lb. Therefore, a train pipe reduction greater than 15 lb. fully applies the brakes and is wasteful of air as the train pipe and the auxiliary reservoir must be fully charged after each application.

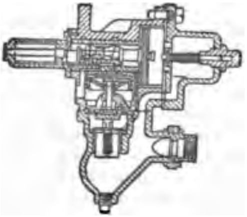


FIG. 24.—Quick action triple valve.

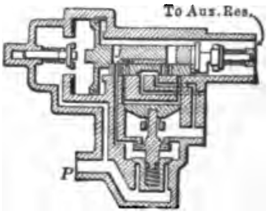


FIG. 25.—Quick action triple valve.

Quick-action Triple Valve. The quick-action triple valve shown in Fig. 24 is designed to be used on freight trains of considerable length, its function is to apply and release the brakes on the rear cars so quickly that the running in and out of the slack is avoided. Fig. 25 is a diagrammatical section of the triple valve shown in Fig. 24. In the full release position shown, air is allowed to pass from the brake cylinder through ports in the slide valve, the same as in the plain triple valve. The auxiliary reservoir is charged through grooves around the slide-valve piston and through the raised check valve and uncovered port in the slide valve.

In release position the decrease in train line pressure allows the valve piston to move to the left closing the charging grooves and feed port, J, and exhaust port, P. Just previously to the valve piston striking the graduating stem, a cavity in the grading valve on top of the slide valve connects ports which allow communication from the brake cylinder to the emergency chamber and train pipe. The piston in the emergency chamber is only loosely fitted so that the air which is admitted from the train pipe to the unseated check valve passes into the brake cylinder before communication is established between the auxiliary reservoir and the brake cylinder. Owing to the friction in the train pipe a reduction of air pressure at the front end of the train is not felt at the rear end until some time later, thus the venting of the train pipe at each car results in hastening the reduction for each car following; at the same time requiring a less reduction at the engineer's valve to apply the brakes with a given pressure since the auxiliary reservoir is not required to supply all the air to the brake cylinder.

When the brake-cylinder pressure is reduced below that in the train line, the slide-valve piston moves to the right with the graduating valve and closes all ports leading to the brake cylinder. The tendency for the brake-pipe and auxiliary-reservoir pressures to equalize through the connections to the brake cylinder is prevented by the proportioning of the respective ports, so that the auxiliary-reservoir pressure decreases faster than the brake-pipe pressures and insures the travel of the piston to the right.

In retarded release the train line is quickly re-charged, forcing the valve piston to the extreme right, thus preventing the re-charging of the auxiliary reservoir through the charging grooves before opening a small port in the slide valve, thus permitting the train-line pressure to raise the check valve and slowly re-charge the auxiliary reservoir. The function of the charging device (shown on the outside of the valve in Fig. 24) is to prevent the inertia of the slide valve forcing it to the extreme right of its travel when the valve piston is brought up against its stop. The restricted area at the left end of the exhaust cavity of the slide valve partly closes the exhaust port and allows the brake-cylinder air to flow slowly into the atmosphere. On account of the friction in the train pipe, it is impossible to re-charge the train line at the rear of the train faster than the air will flow through the charging grooves of the triple valves, hence only the triple valves of the foremost cars move to retarded release, the others remaining in full release, thereby releasing the brakes on the rear cars quickly.

The sudden reduction of train-pipe pressure in emergency position of the engineer's valve moves the slide-valve piston to the left compressing the graduating spring and opening a port directly to the brake cylinder and another to the emergency chamber unseating the emergency valve; at the same time the train-line pressure opens the check valve and air flows from the train-line directly into the brake cylinder, applying the brakes with maximum pressure. The quick venting of the train line insures the rapid serial action of the brakes on the rear cars. The braking of a hose opens the train-line, thus reducing the train-line pressure and causing the brakes to be applied.

Combined Straight and Automatic Air Brake Equipment. With the combined straight and automatic air brake equipment, when the motorman's valve handle is placed in the emergency position, air is admitted to the brake cylinder on the operating car by both the automatic and straight air features, giving a maximum brake cylinder pressure, which is maintained as long as the handle remains in this position. The change from the straight air application of the brake to an automatic application, or *vice versa*, may be made by moving the valve handle to the different positions on the valve quadrant. An automatic application of the brakes on the entire train is made by moving the valve handle to the automatic service position, which reduces the pressure in the brake pipe in the usual manner. A straight air application of the brake is made by moving the valve handle to the straight air application position. This connects the control pipe with the straight air application pipe and admits air to the brake cylinder through the quick service valve from both the straight air application pipe and the auxiliary reservoir. The release of the brake is made, after a straight air or an automatic application, by moving the valve handle to the release position. In this position the control pipe is connected to the brake pipe, and the straight air application pipe is connected to the atmosphere. A straight air application pipe, which connects the motorman's valves with the quick service valve, is installed on motor cars only. For automatic operation, two pipe lines, namely the control pipe and brake pipe, are provided on each car. These are connected together between cars by standard hose and couplings, making them continuous throughout the train. The control pipe admits air at a pressure predetermined by the adjustment of the feed valve (usually 70 lb.) to the reservoir connection of the motorman's valve, and also to the triple valves on all the cars in a train. This arrangement confines the excess pressure of 85 or 95 lb. to the main reservoir, and thus prevents overcharging the brake pipe and auxiliary reservoir. This arrangement automatically provides for an even distribution of work between the several compressors on a train, without the use of any special governing apparatus.

The following list of advantageous features of this system were given in a paper by Mr. W. V. Turner, Electric Journal, 1911: (1) Flexibility and promptness of a straight air operation providing a brake easy to manipulate, quick and uniform in response, thereby saving much time in making stops; (2) all the features of straight air and, in addition, an automatic brake for safety; (3) both straight air and automatic operations by movement of one brake valve handle; (4) both straight air and automatic operation without interference with or sacrificing any of the normal functions of either; (5) a "straight-air-in-emergency" feature through the brake valve to brake cylinder, thus insuring a maximum and maintained brake pressure at the time most needed, regardless of the condition of the triple valve; (6) especially adapted to cars used in switching service or for occasionally handling freight or other cars equipped with automatic brakes; (7) both brakes must fail before the brake is lost.

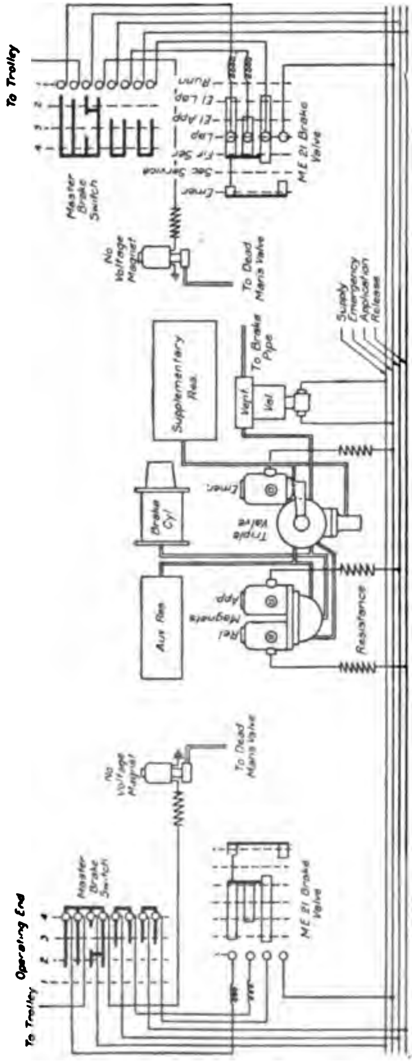


FIG. 26.—Electropneumatic brake equipment, New York Subway.

Electropneumatic Brake System. (Fig. 26.) The electropneumatic equipment consists of a quick action, quick re-charge, quick service graduated release automatic air brake with about 30 per cent. higher pressure in emergency application, combined with electrically controlled means of simultaneously admitting air directly to or releasing it directly from the brake cylinders without any movement of the triple valves. Means have also been provided whereby a simultaneous movement of the triple valves of the train to emergency position is obtained by the use of electricity.

For the operation of the electrical portion of this system the current may be taken from trolley or from a battery or other source of supply local to each car. The contacts in the electric portion of the brake valve are small controller points or switches, controlling the circuits to magnets governing the service application and release and emergency portion of the brakes. With the pneumatic portion of the brake in normal or running position, the electric control of the brakes is accomplished by the aid of two magnets with poppet valves attached, governing the flow of air into and out of the brake cylinder direct or through the release port of the triple valve, according to the conditions of installation. The release magnet may be designed so that the release port is open only when the magnet is energized, or so that current is required in order to close the release magnet. Which method is to be preferred can only be determined by a study of the operating conditions. In either case, while running over the road the exhaust magnet is holding the release valve open so that the brake cylinder is in direct communication with the atmosphere. In making a service application of the brakes the exhaust valve is closed and the application magnet is energized to open the application valve. The flow of air from the source of supply to the brake cylinder is controlled primarily by a relay valve, which, in turn, is caused to operate by the action of the application magnet valve. This does away with the necessity for the very powerful magnet which would be required to operate a large enough valve to supply air to the larger sizes of brake cylinders at a sufficiently rapid rate to give satisfactory service operation. The relay valve referred to is acted upon by a spring so that when the brake cylinder pressure has been built up to within 20 lb. of that in the auxiliary reservoir it automatically closes. This valve, therefore, limits the pressure obtainable in electric service application to approximately 20 lb. below the normal brake pipe pressure, thereby incurring the valuable feature of increased braking power in emergency applications over and above that obtainable in full service applications and this without the aid of any additional device, such as a safety valve. After being raised to any amount up to the maximum contemplated in the design, the brake cylinder pressure can be maintained as long as desired by moving the brake valve handle back to electric lap position, which leaves the release magnet undisturbed but de-energizes the application magnet, allowing it to close and prevent further flow of air into the brake cylinder. A further application of the brake or a release can then be made by moving the brake valve handle either to electric application or to release position, which either causes more air to flow to the brake cylinder, as described above, or operates the release magnet valve so as to permit the air in the brake cylinder to escape to the atmosphere. If, when making a release, the brake valve handle is returned from release to electric lap position, the release magnet will again be actuated so as to close the brake cylinder exhaust. In this way the brakes can be gradually released in any desired number of steps or graduations. During the electric operation of the brake, the feed port of the brake valve is open and the communication between feed valve and brake valve is maintained. Consequently, the air which is drawn from the auxiliary reservoir for use in the brake cylinders is continuously replaced from the brake pipe, which is in turn kept fully re-charged through the feed valve. Should the motorman continue the movement of the brake valve handle beyond electric application position, the brakes will continue to apply up to their predetermined maximum pressure until the handle is moved so far that a pneumatic application is begun. That is to say, the motorman cannot go beyond the point at which an electric application will cease to be made until after he has come into a position in which a pneumatic application is commenced. There is thus no possibility of a motorman failing to obtain an application of the brakes or losing an application already obtained electrically on account of moving the brake valve handle too far.

Electric Emergency Applications. The quick action and emergency electropneumatic operation is accomplished by adding an emergency contact finger to the brake valve, an emergency wire running throughout the train and an emergency magnet with its valve controlling a port leading from the face of the triple valve piston direct to the atmosphere. In order that an emergency application originating from the trip or conductor's valve, burst hose, etc., may be propagated electrically as well as when an emergency application is made by the motorman moving the brake valve handle, each brake-pipe vent valve is provided with contacts whereby the operation of any vent valve in the train will energize the emergency magnets in the same manner as when the brake valve handle is moved to emergency position.

Mr. M. V. Turner, Electric Journal, 1911, gave the following list of advantageous features which the electropneumatic brake adds to the highest type pneumatic system and which are impossible of attainment otherwise: Simultaneous and uniform response of all the brakes in the train, which means the ability to obtain perfect results with the least skill and experience, regardless of the length of the train; double protection against delays to traffic, due to brake failure, since the pneumatic brake is always in reserve ready for use, if required; maximum efficiency and safety due to simultaneous operation of all the brakes in the train, in both service and emergency application, and a perfect flexibility of manipulation; economy in air consumption and maintenance of brake cylinder pressure at will.

Air Brake System for Low Floor Car. Fig. 27 shows the general layout of the Westinghouse brake equipment which has been installed on the New York low floor cars. The use of the emergency feature, combined with the ordinary straight air operation for service applications, permits full braking power to be obtained practically instantaneously in three different ways, namely: (1) when the motorman places the handle of the brake valve in emergency position, (2) through the accidental release of the button on the controller handle by the motorman, and (3) if the conductor operates a valve located overhead within convenient reach. The equipment also provides for two-car train operation, and in the event of two cars separating accidentally, the brakes on both vehicles are applied instantaneously without the necessity of any manipulation on the part of either the motorman or conductor. The compressor which supplies air for the car is located in one corner of ab below the motorman's seat. From the compressor the air passes to the main reservoirs, which are made up of four 16-ft. lengths of 3½-in. light-weight steel boiler tubing running through the openings in the pressed-steel roof car lines. With the exception of the pipes that lead down to the brake cylinders, brake valves, etc., all of the piping is located in the 6-in. space between the ceiling and the roof, hence when once installed properly it is free from the accidental derangement that frequently occurs when cars get off the track. The operation of the compressor is controlled by a governor such as is supplied with the straight air brake equipments. The governor is set to cut in at about 58 lb. and out at 72 lb. The construction of the car necessitated the use of a brake cylinder at each end (see p. 495), and in order to provide for the quickest practicable building up of brake cylinder pressure in emergency application a separate emergency valve is used for each of the two brake cylinders. Two pipes lead from these emergency valves, which, like the reservoirs, are located in the space between the ceiling and the roof, to the brake valve in either cab. This brake valve is of the straight air type, with an emergency position for the handle, and by its manipulation the emergency valve connected with it can be operated either in single- or two-car train service. In each cab there is attached to the main reservoir pipe a dead man's valve that is controlled by the button on the handle of the master controller. If the button is released when the controller is in one of the running positions, the dead man's valve opens, reduces the pressure in the train-line pipe shown in the accompanying diagram and causes the emergency valves to let full air pressure into the brake cylinders.

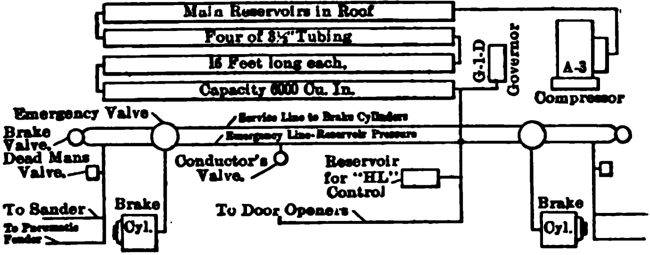


FIG. 27.—Air brake piping for low floor car.

Magnetic Brake. A form of magnetic brake in which are embodied both a track and wheel brake is shown by Fig. 28. A track brake-shoe is placed between the two pairs of wheels and is drawn to the rails by an electromagnet which is suspended from the car, thereby not merely adding its friction to the friction of the wheel brake, but also actually increasing the rail pressure of the wheels to the extent that the supporting springs for the track shoes and magnets are in tension through the descent of the track shoes to the rails. The electromagnet *a*, dividing the track brake-shoe *b* into two parts, is secured by pins to the two push rods *c*, and suspended at a proper distance above the rails by the adjustable springs *h*. The push rods are secured by pins to the lower ends of the brake levers *d*, which are connected at their upper ends by the adjustable rod *g* and are pivoted at an intermediate point to the brake-shoe holders *e*, carrying the wheel brake-shoes, and the hanger-links *f*, suspended from the truck frame. The push rods *c* are telescopic, so that a movement of the track shoe toward the right, relative to the truck frame, causes the wheel brake-shoe at the right to be applied to the wheel and the connection *g* to be moved to the left, thereby applying the wheel brake-shoe at the left, the stop *i* preventing the lower end of the brake lever at the left from following the track brake-shoe. A relative movement of the track brake-shoe to the left is accompanied by application of the wheel brake-shoes through corresponding movement of the parts in the reverse order.

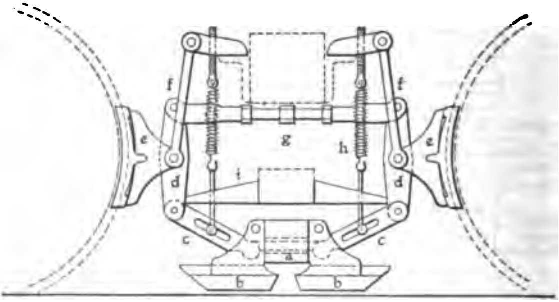


FIG. 28.—Magnetic brake.

The brake-controlling device may be incorporated in the running controller or may be a separate device, placed by its side and operatively interlocked with it, so that neither can be caused to interfere with the operation of the other. In the operation of the apparatus, the current is supplied by the motors running in multiple as generators—the trolley current being entirely cut off—and is divided between the electromagnets and the diverter combination in such ratio as to cause the track brake-shoes to be drawn upon the rails with a force proportionate to the braking requirements. The frictional resistance of the rails to the motion of the track shoes causes the wheel brakes to be applied with corresponding force. Thus, to the ordinary retardation of the wheel brakes is added that of the track brake and also the back torque of the motors, which latter, however, is practically limited to compensation for the rotative energy of the motor and car wheels. The force of application depends primarily upon the current and upon the electromagnets operating the brake-shoes. The attractive force of the rails upon the magnets is under the control of the motorman up to a limit of about 150 lb. per square inch of brake-shoe surface in contact with the rails. The strength of the magnet is limited by the sectional area of the rail acting as armature, and where the weight of the car makes a magnet of greater strength desirable, the track shoe is divided into three parts, instead of two, and wound to form a three-pole magnet, or two combined two-pole electromagnets with one common pole. The friction of the track brake-shoe may also be adjusted to some extent through the angular inclination of the push rods *c*, by which some of the weight of the car may be thrown upon the track shoes, the levers *d* being correspondingly adjusted to reduce the wheel brake-shoe pressure in proportion as the weight is transferred to the track shoe. The current declines with the speed during a stop, thereby offsetting the increased coefficient of friction at the lower speeds. In bad weather, when the condition of the rails is likely to be accompanied by wheel-sliding, the braking force operating the wheel brake is correspondingly reduced, so that the force of application of the wheel brake is automatically proportioned to the rail friction which rotates the wheels. But, in addition to this valuable feature, if by chance the wheels should slide upon the rails, the interruption of wheel rotation is accompanied by the cessation of the track-magnet current, through which the pressure of the brake-shoes upon the wheel is instantly relaxed and rotation of the wheels is resumed, without injury or serious loss of time.

Braking by Regeneration. The process of saving energy of a moving train that would otherwise be consumed in heating the brake-shoes and car wheels is discussed under "Regeneration" (see page 213). In furnishing this energy of regeneration the speed of the train is reduced without wear and tear and excessive heating of brake rigging, brake-shoes and car wheels. The possibility of accident from these sources is thus reduced, and on long mountain grades the safety of operation due to the braking feature of regeneration may be of more importance than the saving of energy. The application of air brakes during the process of regeneration may reduce or destroy the regeneration and its braking action and might bring an excessive load on the brakes by causing the motors to take current from the line.

Braking by Reversing Motors. A retarding force may be applied to the train by reversing the motors and applying current to them through a portion of the starting resistance. This method should be used only in an emergency, as it strains the car equipment, and if the direction of rotation of the wheels is reversed the braking action will be of low efficiency because of the low value of coefficient of friction between the slipping wheels and rails.

Braking by Bucking Motors. If two series motors whose armatures are revolving but to which no current is supplied from an external source have their connections suddenly reversed and then placed in parallel, they will tend to operate as series generators; the one of higher potential will continue to act as a generator and drive current through the other which will consequently act as a motor. This action will retard the motion of the armatures. The steps necessary to make use of this action in retarding the motion of a car are: Open circuit breaker, throw reverse lever to the position corresponding to motion opposite to that of the car and move controller handle to a parallel notch. On a four-motor car, where pairs of motors are permanently connected in parallel, the last step noted is unnecessary. It should be noted that if the current supply to a car ceases as the car is ascending a grade and it is desired to use this method of braking to keep the car from backing down the grade, the reverse lever should be left in the position corresponding to the forward motion of the car up the grade. This method of braking should be used only in emergency.

Brake Inspection (A.E.R.E.A. Approved Practice). Start the air pump and allow it to pump to its maximum capacity; see that brake valve handle is in release position, and where automatic air is used see that gage hands show a difference between train line and auxiliary of 20 lb. If they do not, the governors need to be reset. Apply brake to show reduction of 40 lb.; place brake valve handle to lap position; see that air gage operates properly and that no leaks are in or around the brake valves or pipes leading thereto; examine all pipes, reservoirs, triple valves, cylinders, etc., while brake is set, and see that none are leaking and that brake does not release while the brake valve handle is in lap position. If the cylinder piston has a travel of more than 5 in. an adjustment of brakes is necessary. Inspect all shoes and see that they are in alinement with the wheel and that none are broken, and renew those that will not give sufficient wear until the next inspection. In renewing brake-shoes put shoes of the same thickness on opposite wheels, be they either old or new. See that all brake-shoe keys are in place and that none are lost or broken; examine shoe heads and see that none are lost or broken, and that all pins, bolts, etc., that hold heads to the beam or truck levers are not unduly worn; that all bolts, cotter pins, nuts, etc., are in good condition. Examine brake beams and see that none are cracked, broken or bent, and that all bolts, pins and holes are not unduly worn, and that all cotter pins and nuts are in place. Examine all hangers and pins connecting brake-shoe head and beam to truck and see that all are in good condition, and that none of the pins and hangers are unduly worn so as to cause brakes to grab or chatter; special attention must be paid to all cotter pins in all parts of the brake rigging. Examine all turn-buckles and see that none of the threads are stripped and that all adjusting and jam nuts are tight and in their proper places. Adjust brakes so that cylinder piston will not travel more than 4 or 5 in. When brake is in release, see that none of the shoes bind the wheels, that release springs operate properly so that brakes will be free when released. Examine all pull rods for cracks or flaws, all pins in pull rods, levers and slides; set hand brake and see that it is in good condition; see that brake staff and chain are not unduly worn; that rod, pins, etc., are in good condition. Where slack adjuster is used, see that it is placed to its minimum of travel before any adjustment of brakes; see that it is operating properly and that it has not traveled to a maximum position, leaving the correct piston travel. Drain all reservoirs daily.

Maintenance of Motorman's Valve. The seats of the rotary or motorman's brake valve are subject to the collection of dirt largely because of the passage across them of air which is more or less laden with dust. When this collection causes the valve to work hard or the valve seat becomes badly scored, the attempt to grind the surfaces with emery should not be made. Grinding with emery generally causes leaks between the ports and an attempt to grind out cuts or scores will usually make the valve worse. When the condition of the valve becomes so bad that the valve cannot be kept in service it should be machined and scraped by hand to a perfectly flat surface, using a face plate to locate the high spots.

Inspection of Air Compressors. The frequency of inspection necessary for an air compressor depends upon the service required of the compressor. The duties of air compressors on city and interurban cars vary greatly. For instance, a car may be equipped with air doors, electropneumatic control and air brakes. The average number of stops of a car of this character in city service may be every 1500 ft. A compressor under these conditions would necessarily have to be overhauled much more than one which makes stops 2 or 3 miles apart, has no air doors or electropneumatic control. The A.E.R.E.A. 1908 Committee on Maintenance and Inspection recommended that the inspection period for compressors in the former class of service be 600 miles and that for the latter class be 1200 miles. In the above report it was recommended that air compressors be inspected as follows: Oil plug should be removed and oil added to replace what has been lost in service each inspection day. Carbon brushes removed and inspected each inspection day. Brush-holder tension inspected each inspection day. Brush holder wiped off each inspection day. End of commutator wiped off each inspection day. Hair should be taken out of hair strainer and strainer washed in gasoline every thirtieth inspection day. Valves should be taken out and cleaned in gasoline each thirtieth inspection day. Exterior of pump should be wiped off each inspection day. Compressors should be thoroughly blown out with compressed air each tenth inspection day.

Air Compressor Tests. The following tests of the air compressor after inspection were recommended in the same report: With all air reservoirs empty and brake valve on release position, start air compressor and note length of time taken in pumping up, and pressure at cutting-out point. A test for leakage should then be made, leaving apparatus in same condition as above, and noting number of pounds drop in 1 minute.

Lubrication of Air Compressor. (A.E.R.E.A. Approved Practice.) Air compressors should be lubricated weekly. Before removing plugs, wipe all dirt and surplus oil from around the openings, then remove plugs and do not fill to an extent to overflow, thereby allowing the oil to collect with the dust and dirt around the pump frame and case. See that the plug threads are in good condition and oil-tight when closed.

Overhauling Air Compressor. The A.E.R.E.A. 1908 Committee on Maintenance and Inspection expressed the belief that with a compressor designed for sufficient capacity for the service it is to perform an overhauling for the former class of service outlined above (Inspection of Air Compressors) should be made every 60,000 miles, and for the latter class of service every 120,000 miles. The overhauling suggested is as follows (A.E.R.E.A. Miscellaneous Approved Methods and Practices): Compressor should be taken from under the car and placed on a bench, where armature should be removed, oil drained from crank case and all bearings outside of crank case, and bearings thoroughly washed out with gasoline. Crank shaft and connecting rods should have slack taken up on them or bearings re-babbitted or relined with bronze bearings, as the case may be, if wear is excessive. Head should be taken from the compressor, ports scraped out, hair removed from hair strainer and washed in gasoline, and valve and valve seat should be re-ground. Armature should be blown out, cleaned up and breakdown test applied. Also commutator trued up. Mica retaining rings should be painted with insulating paint. Armature painted with a coat of oil-proof insulating paint. Brush holders should be cleaned in gasoline and overhauled, replacing worn tips and shunts that have broken strands. Field coils should be taken out and insulation carefully looked over, and replaced if necessary. Inside of the motor shell should be carefully cleaned with gasoline to get oil and dirt out of shell. The impregnation of pump field coils is recommended as tending to eliminate field troubles and greatly prolong the life of the fields. The piston should be removed from pump, and rings removed from groove and carefully cleaned; also, groove should be carefully scraped out. Springs from piston rings should be tested to make sure that they have not lost their tension. If, when pump is re-assembled and started to work under pressure for 5 minutes, it be then disconnected and allowed to run free and oil is discharged from the outlet, it is an indication that the rings are not tight enough in the cylinder, and springs of greater tension should be put in the rings. The insulators placed between compressors and air piping on car should be taken from the car and cleaned and given a breakdown test of 1000 volts. The oil which was removed from the compressor when it was removed for inspection should be run through a filter and returned to compressor, enough oil being added to take the place of the dirt, etc., which it contained when removed. In this connection care should be taken to use an oil which does not contain asphalt or which carbonizes when the pump is given hard usage.

Storage Air Brake System. In the storage air brake system the service reservoir is supplied with air from storage reservoirs (generally two) carried on the car. These storage reservoirs are charged with air at high pressure from compressor stations along the line. The air is passed through a pressure-reducing valve between the car storage reservoir and the service reservoir, and thus its pressure is reduced to a valve proper for service in the braking system.

Whether or not the storage system should be used rather than the individual car compressor for a given service must be decided from local conditions. The storage system may in some cases be cheaper than the individual car compressor system, but the many advantages in having the car self contained, as by the use of the individual car compressor, make the use of the latter system most general. Moreover, air-operated auxiliaries demand air in addition to that for the brakes and such demands will, in most cases, make the employment of the storage system impracticable.

Size of Air Compressor Required for a Given Service (A.E.R. E.A. Approved Practice). An air compressor should be of a size such that it will not be required to operate more than one-third the time. In connection with the above, due consideration should be given the air requirements of air-operated doors, sanders and other auxiliary equipment.

Air Compressor for Operation on 600 and 1200 Volts. If the compressor motor is wound and insulated for operation on 1200 volts, it will operate more slowly on 600 volts, and to furnish the same quantity of air it will therefore be required to run longer on 600 volts than on 1200 volts. For this reason a compressor selected for a given service on the two voltages should be of such a size that it will not be overworked on 600 volts.

Dynamotor-compressor for 600–1200 or 750–1500-volt Operation. (See Fig. 29, also p. 573.) In the dynamotor-compressor, the compressor is driven by the dynamotor through a pneumatically operated multiple-disk clutch controlled by the pump governor. This arrangement obviates the necessity of a separate motor to drive the compressor. When the air-pressure governor, set for some predetermined pressure, acts, it opens a valve admitting air to cylinder adjacent to the clutch. A piston in this cylinder operates against a heavy spring in such a way as to disengage the clutch. When the tank pressure reaches a minimum value, the air in the cylinder is automatically released by the governor, the spring closes the clutch and the compressor starts. The dynamotor armature has two separate windings on the same core, each connected to a commuta-

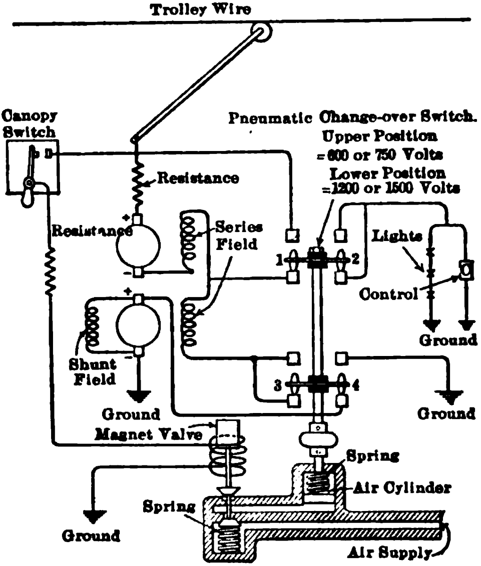


Fig. 29.—Connections for dynamotor and change-over switch.

tor. Each armature winding is in series with half the series field and these armatures and fields are in series with each other on 1200 or 1500 volts, thus giving a half voltage tap at a point between the two field windings. A shunt field winding is connected across the low voltage armature to maintain the speed approximately constant. The speed on 600 or 750 volts is approximately the same as on 1200 or 1500 volts, respectively, thereby maintaining the air compressor capacity on the lower voltage. A change-over switch for changing the dynamotor connections from those for 1500 to those for 750 volts (or from 1200 to 600 volts) trolley or third rail potential simultaneously changes the lighting and control circuit connections from the dynamotor terminals to the trolley or third rail. This change-over switch is pneumatically operated and is controlled by a canopy switch located in the cab. It consists of a single magnet valve and a pneumatic cylinder similar to those used on Westinghouse switch groups. It carries a double pair of contacts which establish the proper dynamotor and auxiliary circuit connections. Normally, this switch is held in the high voltage position by a powerful spring. But, when desired, it can be held in a low voltage position by the admission of air to the pneumatic cylinder. In case of a failure of either air or electric power the switch automatically returns to the high voltage position which is safe at either voltage.

Air Used and Electrical Energy Required to Drive Compressor. The data in the following table were taken from the Report of the Electric Railway Test Commission, 1906, and were based on tests made by the Commission on cars in operation in St. Louis.

	Storage system	Individual car compressor system, dry track	Individual car compressor system, wet track
Average number of stops per mile....	5.9	4.1	4.5
Schedule speed of car, miles per hour	9.12	9.5	9.3
Maximum speed of car (approximate), miles per hour	17.5	16.0	16.0
Average volume of free air used, cubic feet per car per stop.	1.43	1.68	1.51
Average volume of free air used, cubic feet per ton per stop.	0.064	0.076	0.067
Electrical energy for compressing air, watt-hour per car per stop.	8.25	6.74	5.86
Electrical energy for compressing air, watt-hour per ton per stop.	0.367	0.306	0.261

General Characteristics of a Good Air Compressor. An air compressor should be reliable, of light weight and compact construction, should be protected from dirt and water, should be so constructed as to be easily inspected, lubricated, overhauled and repaired, should run with the least possible amount of noise and vibration, should have high efficiency of operation and should have a low cost of maintenance.

General Types of Air Compressors. The independent motor-driven air compressor most commonly used for electric railway service may be considered to be of two general parts, namely, the motor and the compressor. If the motor and compressor are geared together, the machine is known as the geared type compressor. If the motor shaft is direct connected to the compressor connecting rod, the machine is known as the gearless type compressor. Because of the absence of reduction gearing a gearless type air compressor differs mainly from the gear type of the same capacity in that the piston speed (revolutions per unit time) of the former is greater than that of the latter, consequently the piston displacement of the former is the less. Compared with a gear type air compressor of the same capacity, a gearless type compressor weighs about one-half, occupies about one-half the space and has a very low overall height. The stresses in the gearless type are much lower, the maximum transverse thrust on the crank being only about one-fifth as much as that in the geared type.

Improvements to Prolong the Life of Air Apparatus. The following important points are from an address by Mr. W. G. Kaylor, Keystone Railway Club: In the latest form of air strainer oil is used to absorb the dirt taken in with the air. The air on its way to the pump does not pass through the oil, but is broken up by perforations or baffle plates which direct the incoming air toward the oil. The dirt is then entrained by the adhesiveness of the oil and settles to the bottom of the strainer, while the clean air passes on to the pump. Compared with the curled-hair strainer, its efficiency is as 98 per cent. to 50 per cent., and for this reason it can be attached directly to the head of the compressor, so obviating the necessity of piping the suction to the roof. The crank-case vent, through which dirt is also liable to enter, is now either fitted with a separate strainer or is connected to the suction by a pipe or cored passage. The proper protection of the intake and crank-case vent would make it possible to operate a compressor in normal service for 10 years or more before bushing the cylinders or renewing the bearings. Deterioration due to corrosion, oxidation, etc., could be postponed indefinitely by enameling the reservoir both inside and out. To guard against explosions from excessive pressure, all reservoirs should be protected by a safety valve set at 10 lb. above the maximum working pressure. The safety valve, in turn, should be inspected regularly to prevent it from freezing shut on account of corrosion. When ordering motorman's brake valves the purchaser should specify types which are provided with renewable bushings. As to brake cylinders, the best grade leather should be used for packing, the expander ring should have a flat surface which distributes its pressure over a greater area than the ordinary round expander ring, and the lubricant should be a compound which will fill the pores of the leather to make it absolutely air-tight.

Brake-shoe Wear. Concerning brake-shoe wear, the 1910 Committee on Brake-shoe Tests, M.C.B.A., recommended that on the cast-iron wheel the shoe wear be determined by making 100 applications of the shoe to the wheel, under a pressure of 2808 lb., and at a constant wheel speed of 20 miles per hour, at each application the shoe to be in contact with the wheel during 190 revolutions and out of contact during the succeeding 610 revolutions. That, under these conditions, the shoe shall lose in weight not more than 0.8 lb. for each 100,000,000 ft.-lb. of work done. That, on the steel-tired wheel, the shoe wear be determined by making 10 stops from an initial speed of 65 miles per hour and under a shoe pressure of 12,000 lb. That, under these conditions, the shoe shall lose in weight not more than 4 lb. for each 100,000,000 ft.-lb. of work done.

That committee recommended the adoption of the following suggestions in place of the then existing specifications for brake-shoes:

a. Shoes shall be tested for coefficient of friction and for wear upon the Master Car Builders' Association testing machine, or upon a machine with equivalent characteristics.

b. Shoes shall develop upon the cast-iron wheel, in effecting stops from an initial speed of 40 m.p.h., a mean coefficient of friction of not less than 22 per cent. when the brake-shoe pressure is 2808 lb., 16 per cent. when the brake-shoe pressure is 6840 lb.

c. Shoes shall develop upon the steel-tired wheel, in effecting stops from an initial speed of 65 m.p.h., a mean coefficient of friction of not less than 12½ per cent. when the brake-shoe pressure is 6840 lb., 11 per cent. when the brake-shoe pressure is 12,000 lb.

d. No limitation is placed upon the rise in coefficient of friction at the end of the stop.

General Performance of Brake-shoes. The following deductions are based on laboratory tests made in connection with the Pennsylvania-Westinghouse tests, 1913:

(*a*) The generation of the retarding forces and consequent absorption of the energy of the moving train is dependent upon but a very small quantity of brake-shoe metal. (*b*) The actual bearing area rather than the total face area of the shoe is the important factor in brake-shoe performance. (*c*) The magnitude of the bearing area changes throughout the stop and is greatest near the end of the stop. (*d*) The bearing area shifts continuously from one portion of the surface to another during the stop. (*e*) The principal factor in producing high friction for any given braking condition is the frequent shifting of the bearing area from the heated to the cooler spots over the face of the shoe. (*f*) Slotted shoes or shoes that are cracked are more flexible than solid shoes and the bearing area shifts more readily than in the case of solid shoes. (*g*) With shoes of the same type and approximately the same hardness, the wear per unit of work done is less with the slotted shoe than with the solid shoe. The stops with slotted shoes were always shorter and the mean coefficient of friction higher than with solid shoes. (*h*) The shifting of the bearing area will tend to be more rapid if the size provides more available area for shoe bearing. (*i*) The greater the pressure per square inch of bearing area, the lower will be the mean coefficient of friction. (*j*) Flanged shoes provide more available area for bearing than unflanged shoes.

"Squealing" During Braking. Opinions based upon tests and given in testimonies at hearings on street car noises agree that "squealing" during braking is due to rubbing of wheel flange against rail head as the freedom of the wheel to seek the path of least resistance is restricted by the brake-shoe pressure. The greatest amount of noise is given off by steel wheels. Reduction of the noise has been sought in lubricating the flange by the use of a brake-shoe of special composition or having inserts of a lubricating material. Among these materials are lead and a composition of graphite and asphalt. The ideal lubricant is the one which may be used at the least cost and which will not reduce the friction between brake-shoe and wheel. On Dec. 19, 1913, an order that cars be equipped with brake-shoes containing a lubricant or with some other effective device for the mitigation of "squealing" was issued by the Public Service Commission for the First District of New York.

Wear, Relative Efficiency and Cost of Various Types of Brake-shoes. The following conclusions were drawn from the results of stand tests and a test by a year's service with 800 brake-shoes on the Brooklyn Rapid Transit System by Mr. George L. Fowler. Four general types of shoes were used in these tests; they are designated as "A," "B," "C," and "D," respectively. "A" was a plain, hard cast-iron shoe containing 1.67 per cent. combined carbon and 1.36 per cent. graphitic carbon. The microscopic structure of the "A" shoe seemed to be between malleable iron and gray cast iron in that the graphite appeared both as nodules and very small flakes. "B" was of cast iron, with ends chilled, containing 1.20 per cent. combined carbon and 1.85 per cent. graphitic carbon. The microscopic structure of the "B" shoe would probably be classified as mottled iron. It differed, however, from the typical mottled iron in the more even balance of the pearlite and graphitic carbon by which the structure more nearly resembled that of hard iron. "C" was of cast iron with an expanded metal filling. "D" was of cast iron with chilled iron inserts in the part bearing on the tread. The coefficient of friction and wear for each of the general types of shoes given in the following table were secured from tests in a brake-shoe testing machine by applying the brake-shoe under a pressure of 6840 lb. and a speed of 20 miles per hour:

COEFFICIENT OF FRICTION AND WEAR

Type of shoe	Coefficient of friction, per cent.	Inches, wear per 100,000,000 ft-lb.
A	39.8	1.79
B	31.2	0.61
C	41.9	1.83
D	29.1	0.47

Conclusions: (*a*) In order to avoid excessive costs for the application of brake-shoes the weight should be limited so that no individual shoe should weigh more than 24 lb. To avoid an excessive loss of weight in the percentage of scrap the minimum weight of individual brake-shoes should be 20 lb. (*b*) There appears to be a close relationship between the microscopical structure of cast iron and its wearing qualities. Hence the foundry practice should be such as to secure a structure that is closely granular, of uniform texture and with the combined and graphitic carbon pretty evenly balanced. The graphitic carbon should be in the form of nodules rather than flakes. (*c*) There is a general relationship between the coefficient of friction as determined on the testing machine ar the stopping qualities of a brake-shoe in service. (*d*) As far as safety of a car is concerned, owing to the ability to stop from speeds common in surface-car service, there is no appreciable difference between any of the shoes tested. The extreme variation at 15 miles per hour, averages but 5 ft., or about 7.7 per cent. At 20 miles per hour it is but 17½ ft., or 16.26 per cent. At lower speeds the difference is correspondingly less. (*e*) Brake-shoe wear averages from 3.75 to 6.5 lb. per 1000 wheel miles. The scrap weights of brake-shoes on the surface lines should not be allowed to drop below 6¼ lb. per shoe. When the scrap weight has reached 5¼ lb. there is danger of cutting the head. The ideal scrap weight is 30 per cent. of the original weight. (*f*) Shoes containing chilled cast iron either integrally or in the form of inserts wear steel wheels more rapidly than those of gray cast iron only. The order of wear of the wheels with the shoes submitted in the total averages of mileage per 1/16 in. of wear is: "A," 100; "C," 88.23; "D," 83.23; "B," 80.32. (*g*) The wear of shoes is largely dependent on the character of the foundation brake rigging and the way in which it is maintained. (*h*) There is a wide range of mileage obtained with individual shoes of the same type. (*i*) A steel wheel will run about 8000 miles per 1/16 in. wear in surface work. (*j*) The cost of brake-shoes only per 1000 car miles is least for the cast-iron "B" brake-shoes with chilled ends. (*k*) The combination of brake-shoe and wheel costs per 1000 car miles places the "A" and "B" brake-shoes about on a par. (*l*) If the price is based on the cost of brake-shoes per 1000 car miles, a higher price can be paid for the plain cast-iron "A" brake-shoe than for the one with chilled ends, because of the decreased cost of wheel wear. (*m*) Where steel wheels are used, both the wear of the wheel and the wear of the shoe should be considered for though a shoe may be very economical in itself, it may have such a severe effect upon the wheel that when both wheel and shoe are taken together the result may not be economical.

Durability of Flanged and Slotted Brake-shoes Compared with that of Plain and Solid Brake-shoes. The following advantages of the flanged and slotted brake-shoes were given by Mr. S. W. Dudley, A.S.M.E., 1914: The superior durability of the plain slotted shoe as compared with the plain solid amounts to 11.7 per cent. under single shoe brake conditions and 5.9 per cent. under clasp brake conditions. The wear of the flanged solid shoes per unit of work done is 19 per cent. less than for plain solid shoes, and for flanged slotted 26 per cent. less than for plain slotted shoes, or 30 per cent. less than plain solid shoes. The wear of plain slotted shoes per unit of work done is 5.4 per cent. less than the wear of plain solid shoes, and the wear of the flanged slotted is 13.2 per cent. less than the wear of flanged solid shoes. For the same amount of work done flanged solid cost 16 per cent. less than plain solid shoes, and flanged slotted cost 23 per cent. less than plain slotted, or 27 per cent. less than plain solid shoes. Approximately 135 per cent. more stops will be required to wear out the flanged solid than will be required to wear out the plain solid shoe; 158 per cent. more stops to wear out the flanged slotted than the plain slotted shoe, and 171 per cent. more stops to wear out the flanged slotted than the plain solid shoe.

A.E.R.E.A. Standard Brake-shoes, Brake-shoe Heads and Key. Figs. 30 to 32, inclusive, show the principal dimensions of the A.E.R.E.A. standard brake-shoes, brake-shoe heads and key with alterations recommended by the 1913 Committee on Equipment, A.E.R.E.A.

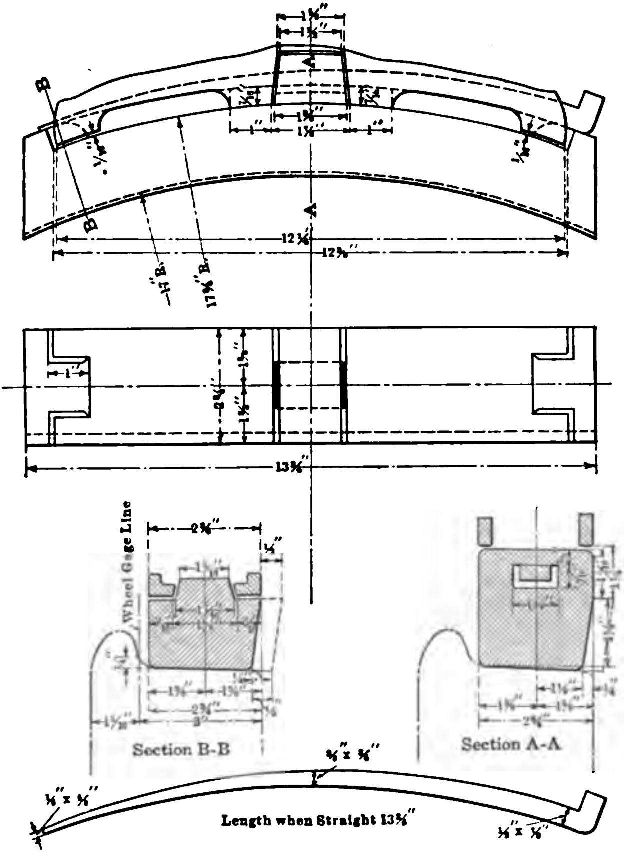


FIG. 30.—A.E.R.E.A. Standard unflanged brake-shoe, head and key for 3-in. tread wheels.

NOTE: For 3½-in. tread wheels, brake-shoe only is changed by increasing the width ½ in. as shown in sections.

M.C.B. Standard Brake-shoe, Brake-shoe Head and Key. Fig. 33 shows the principal dimensions of the M.C.B. standard brake-shoe, brake-shoe head and key.

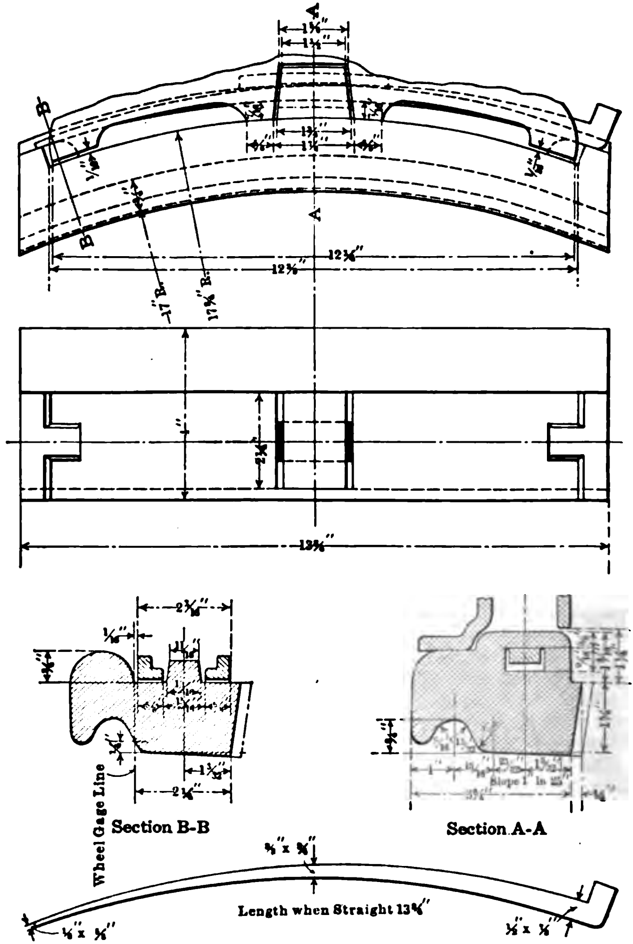


Fig. 31.—A.E.R.E.A. Standard brake-shoe, head and key for 2½-in. tread wheels.

Note: For 2¾-in. tread wheels brake-shoe only is changed by increasing the width ¼ in. as shown in sections.

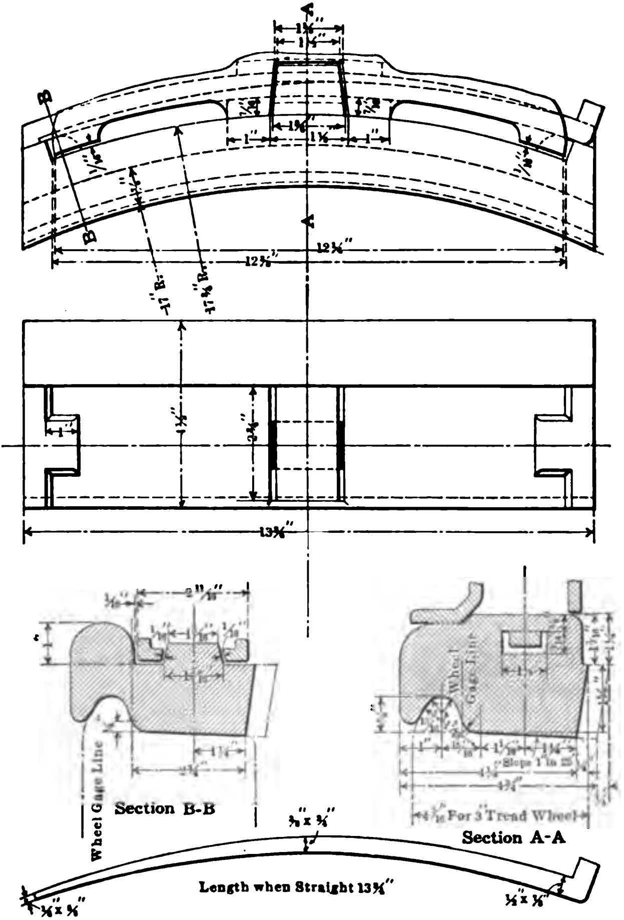


FIG. 32.—A.E.R.E.A. Standard flanged brake-shoe, head and key for 3-in. tread wheels.

NOTE: For 3½-in. tread wheels, brake-shoe only is changed by increasing the width ½ in. as shown in sections.

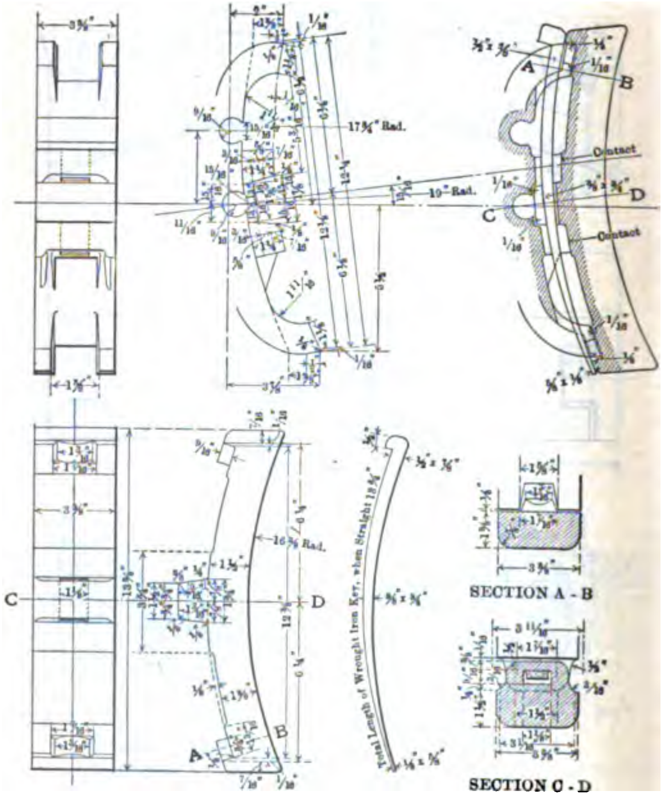


Fig. 33.—M.C.B. standard brake-shoe, head, and key.

SECTION IX

ROLLING STOCK

Car Weights as Affecting Operating Costs. For several years there has been a tendency toward a rational design of cars so as to reduce the weight as much as possible consistent with safety, economical maintenance and life of equipment. As a part of the report of the 1909 Committee on Equipment, A.E.R.E.A., Mr. M. V. Ayres presented a paper on this subject, in which he analyzed the following items of expense which may increase with an increase of car weights; namely, cost of power, cost of car repairs, cost of track repairs, fixed charges of power plant, and fixed charges of distribution system. In all of these cases the cost may be shown in the form of a formula, with a constant plus another quantity almost directly proportional to the weight of car. Mr. Ayres proposes the following formulas:

P = cost of power, in cents per car mile
p = cost of power, in cents per kilowatt hour
n = efficiency of transmission, power house to car
a_p and b_p = constants dependent upon frequency of stops and schedule speed
W = weight of car, in tons

$$P = \frac{p}{n}(a_p + b_p W).$$

For ordinary frequent stop service when the schedule speed is forced up to about the highest point permitted by frequency of stops, Mr. Ayres gives 0.5 and 0.075 as the proper values for a_p and b_p, respectively, although, for ordinary city conditions, he states that the value of a_p may become as low as 0.28.

He also gives the formula: $R = 0.46 + 0.07\,W$ as representing the cost of car repairs, in cents per car mile, as representing average of data on the cost of repairs on a large number of large systems.

For the cost of track repairs, although a certain part of the cost would be incurred irrespective of use, the other proportion is evidently about proportional to ton mileage, and he gives the cost of track repairs, in cents per car mile, as $T = 0.43 + 0.026W$. Here again the relative values of the two constants will depend upon the proportion of natural deterioration to wear, but those given are believed to be fair average values.

Fixed charges on power plant may be taken as some proportional part of the cost of power, and, expressed in cents per car mile, the fixed charges on power plant will then be $C = kP$.

On any railway system a certain minimum investment in poles, trolley wire and feeders is required, and in addition, an investment nearly proportional to the power demand. In cents per car mile, the fixed charges on a distribution system will be $F = a_f + b_f W$. The values assigned to a_f and b_f will vary enormously with different characters of road, being much greater for the interurban than for the city system. Mr. Ayres gives the following as a fair average for an interurban road: $F = 0.32 + 0.02W$.

Total Costs Affected by Car Weights. Summing up the above items and making the following assumptions:

p = \$0.01 = cost of power per kilowatt hour
n = 0.75 = efficiency of transmission, power house to car
k = 0.50 = constant connecting fixed charges on power plant with cost of power

we have as the total cost of operation as affected by car weight, in cents per car mile, $M = 2.21 + 0.267W$.

The application of Mr. Ayres' formula thus gives for the five items of operating costs considered, a cost of 4.88 cents per car mile for the operation of a 10-ton car, the curve rising to 15.56 cents per car mile for a 50-ton car.

Succeeding A.E.R.E.A. committees have given careful consideration to details of the reduction in weight of car bodies, car body accessories, power brakes, trucks, and motive power equipment, and at the present time this important item has every consideration in rolling stock design, although care should be taken to remember the differences in operating conditions. A subway or elevated car cannot be so light per running foot as a surface city car on account of its higher speeds and rates of acceleration and retardation. It is also operated in trains, which makes it necessary to provide for buffing shocks and heavy draft rigging stresses. In the case of the interurban car, weight reduction must not be permitted to go so far as in city cars, as the interurban car is often operated over rough track at high speeds, which necessitates enough weight to insure steady riding; the car may be used to pull trailers, in which case ballasting weight is necessary; the energy consumption of an interurban car operated at relatively infrequent intervals is not so important as on city lines where hundreds of cars may be carrying excess weight; and there is the further desirability of massive construction from the standpoint of safety.

Decreased Weight of Single-ended Cars. The A.E.R.E.A. 1910 Committee on Equipment called attention to the large saving in weight which can be made by the use of single-ended cars, as follows, as applying to double-truck car of the semi-convertible type.

Weight eliminated by making car single-ended:

Step risers, hangers and brackets	306 lb.
Reversing mechanism for seats	108 lb.
Brake rigging	332 lb.
Fender and hangers	125 lb.
Doors, door pockets and operating mechanism	548 lb.
Sand box and mechanism	40 lb.
Brake valve	21 lb.
Air-brake piping	100 lb.
Trolley equipment	140 lb.
Electric equipment, wiring, etc	292 lb.
Headlight	35 lb.
Switch cabinet	75 lb.
Life guards	130 lb.
Snow scrapers	225 lb.
Total saving in weight	2477 lb.

While the equipment advantages of single-end cars are admitted, many operators hesitate to adopt a design which cannot readily be turned back in case of blockades, which call for either Y's or loops at the end of routes, and which is much harder to handle quickly in case of car house fires.

Comparison of Car Weights by Seating Capacity. As it is customary to compare car weights on the basis of seating capacity, the A.E.R.E.A. 1911 Committee on Equipment proposes the following general values for seat dimensions: Width of seat at hip line, 17 in.; height of seat, 17 in.; height of back, 17 in.; distance between centers of transverse seats, 30 in. It was suggested that the dimensions given be used in determining the seating capacity of car spaces not provided with seats, such as baggage compartments and also in determining the seating capacity of longitudinal seats. The custom of comparing cars on the weight per seat basis is quite apt to be misleading on account of variations in arrangement and size of seats, whether the car is single or double ended, whether drop platform or side entrance, etc. It is particularly weak when applied to interurban cars where space must be provided for baggage and express. Taking these things into consideration, the weight per square foot including platform space, or the weight per running foot, should prove more satisfactory.

Economical Size of Car. On the basis of single-car equipment, it is perhaps obvious that the car of the largest capacity which can be run and kept economically loaded, maintaining the proper frequency of cars, will give the least cost per seat or passenger-mile. If multiple unit or trailer operation is used, the fixed charges on a large train may be very greatly cut down, as smaller equipments can be used to much better advantage.

Typical City Cars. Figs. 1 to 16, inclusive, illustrate the floor plan and seating arrangement of cars as standard with sixteen companies operating large surface systems. Most of these cars are of the prepayment type, and the principal dimensions and characteristics of their equipment are shown in the tables on pages 531 to 533.

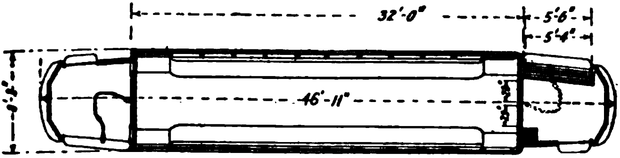
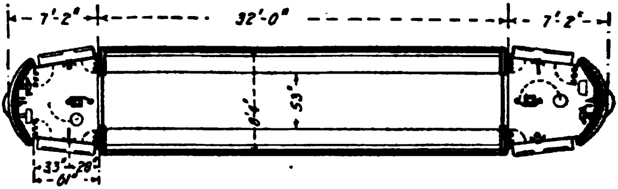


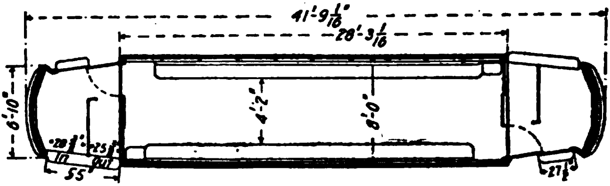
FIG. 1.—New York Railways—47 Seats. Typical city car, end entrance.

It is becoming evident that the ideal car for quick passenger movement is the drop platform type with rear entrance and front exit. Studies which have been made of the center-entrance cars show that they are somewhat slower in loading on account of opposing streams of traffic using the same opening for extrance and exit.

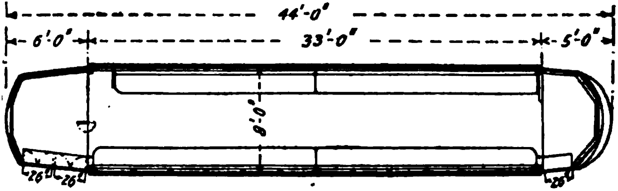
Low Floor Car. The 1914 stepless type of car as used by the Third Avenue Railway, New York, is a most sensible, low ᶠ car, making use of a standard car body and obtaining the



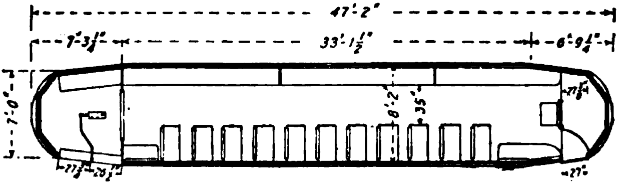
Public Service—42 Seats



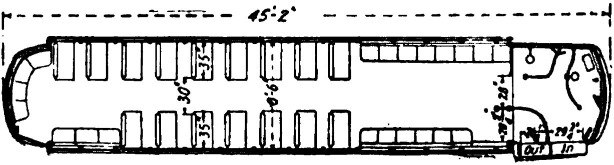
Washington—33 Seats



Cincinnati—33 Seats

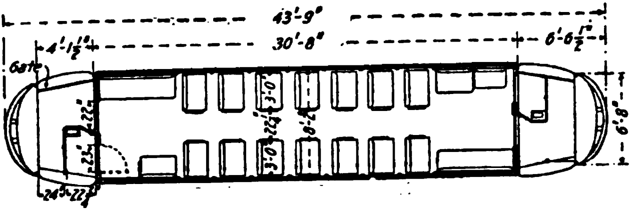


Pittsburgh—56 Seats

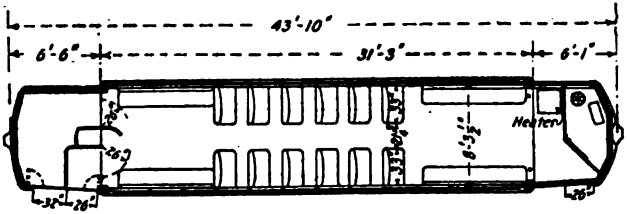


Philadelphia—53 Seats

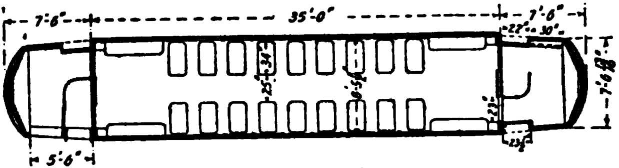
Figs. 2–6.—Typical city cars, end entrance.



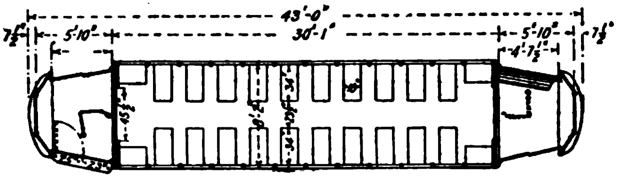
Baltimore—42 Seats



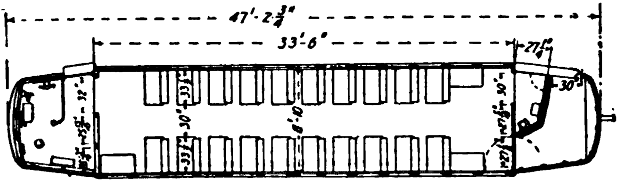
Detroit—48 Seats



Milwaukee—52 Seats

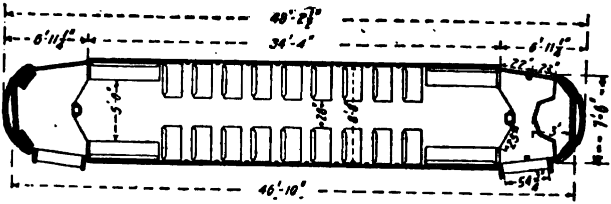


Third Avenue—51 Seats

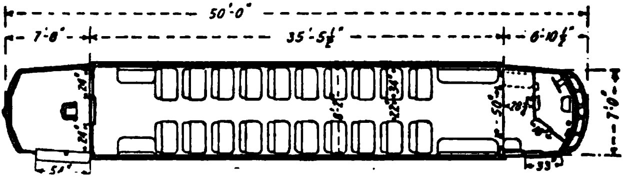


St. Louis—46 Seats

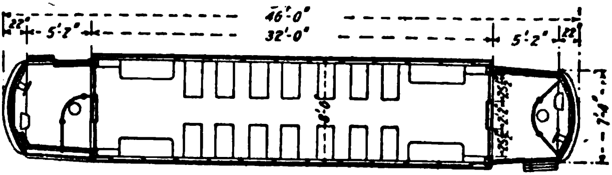
FIGS. 7–11.—Typical city cars, end entrance.



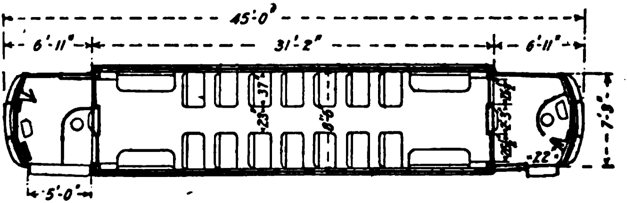
Boston—52 Seats



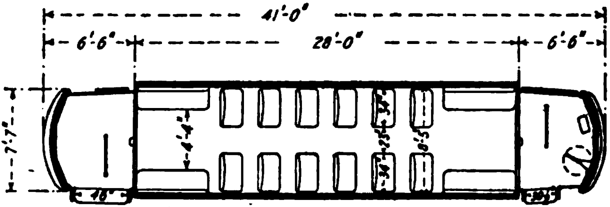
Cleveland—52 Seats



Chicago City—40 Seats



Chicago Railways—40 Seats



Capital Traction—36 Seats

FIGS. 12–16.—Typical city cars, end entrance.

Representative Types of Drop-platform Prepayment Cars

Railway	Type of car	General dimensions				Type of seating	Number of seats		
		Length over bumpers	Length of body	Width over sides	Truck centers		Body	Plat-form	Total
Baltimore	P.A.Y.E. Brill convertible	43′ 9″	30′ 8″	8′ 2″	18′ 8″	28 cross, 14 long	42	0	42
Boston	Easy-access semi-convertible	48′ 2½″	34′ 4″	8′ 8″	24′ 0″	36 cross, 16 long	52	0	52
Chicago City	P.A.Y.E. closed	46′ 0″	32′ 0″	8′ 2⅞″	20′ 5″	28 cross, 12 long	40	0	40
Chicago Railways	P.A.Y.E. closed	45′ 0″	31′ 2″	8′ 3″	19′ 5″	28 cross, 12 long	40	0	40
Cleveland	P.A.Y.E. closed	50′ 0″	35′ 5½″	8′ 2³⁄₁₆″	23′ 5½″	40 cross, 12 long	52	0	52
Cincinnati	Pay-within closed	44′ 0″	33′ 0″	8′ 0″	21′ 0″	All longitudinal	43	0	43
Detroit	Pay-within closed	43′ 10″	31′ 3″	8′ 3½″	....	24 cross, 24 long	48	0	48
Milwaukee	P.A.Y.E. closed	50′ 0″	35′ 0″	8′ 5½″	24′ 0″	36 cross, 16 long	52	0	52
Public Service Ry	Double - entrance pay - on - platform closed.	46′ 4″	32′ 0″	8′ 4″	20′ 0″	All longitudinal	42	0	42
New York Railways	P.A.Y.E. closed	46′ 11″	32′ 0″	8′ 0″	24′ 0″	All longitudinal	42	5	47
Third Avenue Ry	P.A.Y.E. conv.	43′ 0″	30′ 1″	8′ 2″	21′ 5″	40 cross, 11 long	48	3	51
Philadelphia—1911	Near-side semi-convertible	45′ 2″	34′ 1⅜″	8′ 6″	24′ 6″	32 cross, 21 long	53	0	53
Philadelphia—1912	Near-side semi-convertible	45′ 2″	34′ 1⅜″	8′ 6″	24′ 6″	32 cross, 22 long	54	0	54
Pittsburgh	Pay - at - entrance closed	47′ 2″	33′ 1½″	8′ 2″	21′ 6″	23 cross, 29 long	52	4	56
St. Louis	P.A.Y.E. closed	47′ 2¾″	33′ 6″	8′ 8¼″	22′ 3″	40 cross, 6 long	46	0	46
Capital Traction	Pay-within semi-convertible	41′ 0″	28′ 0″	8′ 2″	20′ 0″	24 cross, 12 long	36	0	36
Washington Rys	P.A.Y.E. closed	41′ 9¹⁄₁₆″	28′ 3¹⁄₁₆″	8′ 0″	20′ 3¹⁄₁₆″	All longitudinal	33	0	33

REPRESENTATIVE TYPES OF DROP-PLATFORM CARS.—*Continued*

Railway	Motors			H.p. per ton, light car	Weight completely equipped without passengers, lb.	Weight per seat		Width of aisle, in.	Length of trns. seat cushion, in.
	Type	No. per car	H.p. per car			In body, lb.	Total, lb.		
Baltimore	W–101 B2	4	160	7.44	43,000	1,024	1,024	22¼	32½
Boston	W–306	4	200	7.55	53,000	1,019	1,019	28	32¼
Chicago City	GE–80	4	160	6.21	51,500	1,287	1,287	24	33
Chicago Railways	GE–226	4	140	6.18	45,300	1,132	1,132	23	34
Cleveland	W–101–B6	4	160	6.40	50,000	961	961	22	34
Cincinnati	W–318	2	130	7.51	34,600	804	804	......	......
Detroit	GE–210	2	120	5.58	43,000	895	895	21¾	33
Milwaukee	GE–216	4	160	5.85	54,700	1,052	1,052	25	34
Public Service Ry.	W–307 C	4	160	7.02	45,600	1,085	1,085	......	......
New York Railways	W–310	2	130	6.84	38,000	905	808	......	......
Third Avenue Ry.	W–310	2	130	6.84	38,000	792	745	23½	32
Philadelphia—1911	GE–210	2	120	6.31	38,000	717	717	27½	34¾
Philadelphia—1912	W–306–C	2	120	....	36,520	676	676	27	35
Pittsburgh	W–306	4	200	8.40	47,600	915	850	......	34
St. Louis	GE–216	4	160	6.40	50,000	1,087	1,087	30	33
Capital Traction	W–306	2	100	6.20	32,246	895	895	23	32
Washington Rys.	GE–210	2	120	6.88	34,900	1,057	1,057	......	......

REPRESENTATIVE TYPES OF DROP-PLATFORM CARS.—*Continued*

Railway	Trucks	Controllers	Sanders	No. sq. ft. of standing room in body	Area of rear platform, sq. ft.	Street to step, in.	Step to platform, in.	Platform to car floor, in.
Baltimore	Brill 27-GE-1	K-28-R	Hand	76.70	36.7	15¼	14½	9½
Boston	Brill-27-MC-B 2 Standard 060	West. HL unit switch group.	Poot	96.90	34.17	17	13	10
Chicago City	Brill-27 FE1	K-28-E	Air	90.95	36.99	15	13¼	10⅝
Chicago Railways	Brill-27 GE	K-35	Air	82.50	38.41	15½	13¾	11
Cleveland	Brill-27 FE1	K-35	Air	88.90	45.13	15	14	12
Cincinnati	Brill-39 E	K-40-A	Poot	85.50	29.49	17½	13½	11
Detroit	Standard 050	K-35-D	Hand	83.18	41.95	16	14	11
Milwaukee	St. Louis MCB	K-35-D	Hand	98.90	47.42	16⅞	13 7/16	11
Public Service Ry.	Standard C-50-P	West. unit switch	Air	87.00	35.34	17	13	10
New York Railways	Brill-39 E	K-27	Poot	80.12	38.65	15⅛	13	8¾
Third Avenue Ry.	Brill-39 E	K-27	Hand	63.50	32.73	15⅞	13	9⅝
Philadelphia—1911	Brill-39 E	K-36 F	Air	104.49	[1]45.2	15	14¼	10½
Philadelphia—1912	Brill-39 E	G-36-K	Air	....	[1]45.2	13	13	10½
Pittsburgh	Standard C50	K-43 C	Hand	100.28	28.6	17½	14½	12
St. Louis	Dupont double	K-35 F	Hand	114.20	49.80	16	13	10
Capital Traction	Brill-39 E	K-27	Hand	62.65	35.95	16	14½	9
Washington Rys.	Brill-39 E	K-39	Hand	104.66	36.61	16	13	7

[1] Front platform.

level of end platforms and car floor by the use of a low standard truck with 24-in. wheels as shown on page 416, motors as mentioned on page 241, and air braking system as described on pages 495 and 508. This car body is 23 ft. in length over posts and 35 ft. in length over all, seats thirty-seven passengers in the body and eight more on the platforms. It weighs 24,000 lb., or 533 lb. per seated passenger.

Types of Framing. In the above sixteen types of cars, which were described in a report made in 1912 for the Brooklyn Rapid Transit System by its Mechanical Department, five distinct types of framing were found, as follows:

First. Wooden framing with convex and concave sides, with sills reinforced with steel plates; which type the report states is now practically obsolete, having been superseded by the more extensive use of steel for the principal members, a scientific application of pressed and commercial shapes of steel resulting in a stronger and more durable frame.

Second. The composite framing using heavy steel plates for the lower panels, wood or thin steel for the upper side panels, and wood for the posts and superstructure. This type of construction is commendable on account of the reduction in number of framing parts. A heavy steel plate for the lower outside panel of a car is very desirable from a maintenance standpoint on account of its durability and the resistance it offers against wagon collisions and abrasions. With this type of construction a light wooden superstructure is the most suitable, the upper side panel being of poplar, agasote or thin steel, applied in sections so as to facilitate renewals.

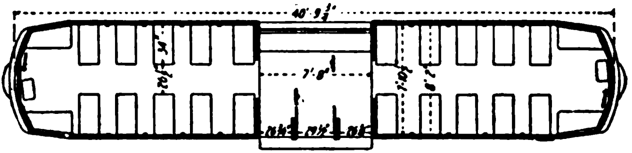
Third. A composite framing using built-up steel girder side construction and steel floor framing with wood or thin steel serving as the outside sheathing. This is a very good construction, but is probably more expensive to build and is heavier because outside sheathing which cannot be counted on for strength is necessary in addition to the inside girder side frame.

Fourth. Semi-steel construction using thin steel sheets on the outside of the body up to the window sill, steel floor members with wood for side posts and roof construction.

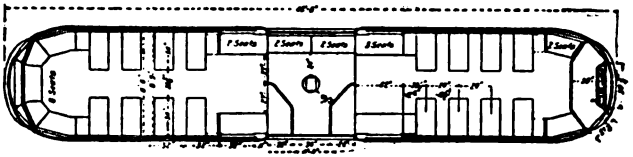
Fifth. All steel body, including side posts with thin sheet steel for outside sheathing and with a steel body plate riveted to the top of the posts to form a girder of the side of the car.

The fourth and fifth types mentioned above are similar except that in the latter the whole side of the car forms a girder to give the necessary strength, while in the former the girder extends only to the window stool. With both of these types it is possible to build a light body and probably no other method produces the same strength at a corresponding weight. An objection to this type of construction is that if the thickness of steel is to be governed by the required strength only, the material will be so thin as to be dented easily by slight collisions. Riveting also becomes difficult and unless corrosion can be positively eliminated, the life of the structure will be comparatively short. If steel of proper thickness to overcome these objections is used, the weight of the car will be very greatly increased.

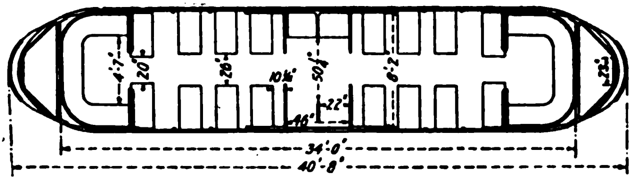
Center Entrance Cars. The floor plans of four cars representative of this type are shown in Figs. 17 to 20, inclusive. The Pittsburgh car is novel in the introduction of an end door, in addition to the center entrances. The principal dimensions and weights of the Pittsburgh car are as follows:



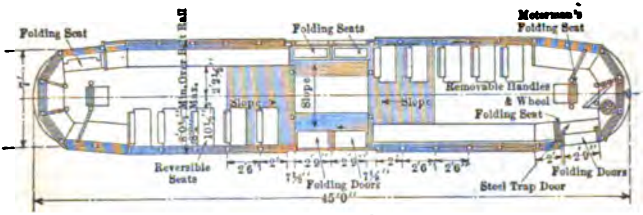
Washington—53 Seats



Brooklyn—58 Seats



New York—51 Seats



Pittsburgh—62 Seats

FIGS. 17--20.—Typical city cars. Center entrance.

Length over buffers	45 ft. 0 in.
Width over all	8 ft. 2 in.
Truck centers	21 ft. 8 in.
Wheel base of truck	5 ft. 6 in.
Size of wheel	24 in.
Height from rail to top roof	10 ft. 6 in.

Weight completely equipped, including couplers	38,000 lb.
Permissible truck-center-plate load	20,000 lb.
Truck center plate, height	19 in.
Weight of each truck without motors	4,220 lb.
Weight of each motor	1,484 lb.
Seating capacity	62
Weight per seat	613 lb.

The design of this Pittsburgh light, low floor car is based on the use of a specially designed motor of the inside-hung, spring-supported type which is drawn out along the shaft and small in diameter. This construction was necessary in order to obtain space for the material required in a motor of the desired capacity, the maximum allowable diameter being restricted by the small diameter of 24 in. of the driving wheels.

The Articulated Car. The articulated car, as adopted in Boston, is shown in plan and elevation by Fig. 21. This car was specially designed for the safe and economical handling of traffic in narrow and crooked streets, and in its assembly of existing rolling stock units of small carrying capacity by means of a central or intermediate compartment, it utilizes a large present investment in equipment which may be no longer best suited to the requirements. The intermediate compartment affords a flexible connection between the two ends and is used for entrance and exit purposes only. The flexible connection enables the articulated unit to traverse any curve which either of the 20-ft. cars of which it is built could negotiate alone, and no difficulty is experienced in operating the car on curves of 35-ft. radius. The middle compartment is carried close to the street, forming a low entrance step 14 in. above the rail.

Double Deck cars have always been popular in Great Britain, but not particularly so on the continent of Europe where the practice, so far as this feature is concerned, is like that in America. Of late years, however, the development in the design of cars with very low floors, and also the perfection of rapid fare collection facilities, have together made the double deck car much more practicable, and it is being operated on some American railways. Within the last 2 years, cars of this type have been put in operation in Pittsburgh and in New York City, and the general arrangement of these cars is as shown in Figs. 22 and 23. The seating capacity of the Pittsburgh car is fifty-two on the upper deck and sixty on the lower deck, with a weight of 375 lb. per seated passenger. The New York car weighs, on the basis of eighty-eight seated passengers, 522 lb. per passenger, but the total standing and seating capacity of this car has been found to reach the high figure of 171 passengers, and on this basis the weight of each passenger carried, standing and seated, is 266 lb.

The double deck car as used in Columbus, Ohio, is a duplicate of the one in New York, and the reasons for the selection of this type at Columbus are contained in the comparative table, shown on page 540, furnished by Mr. A. St. George Joyce, which compares the operating expenses, initial cost and carrying capacity of the double deck cars with other types.

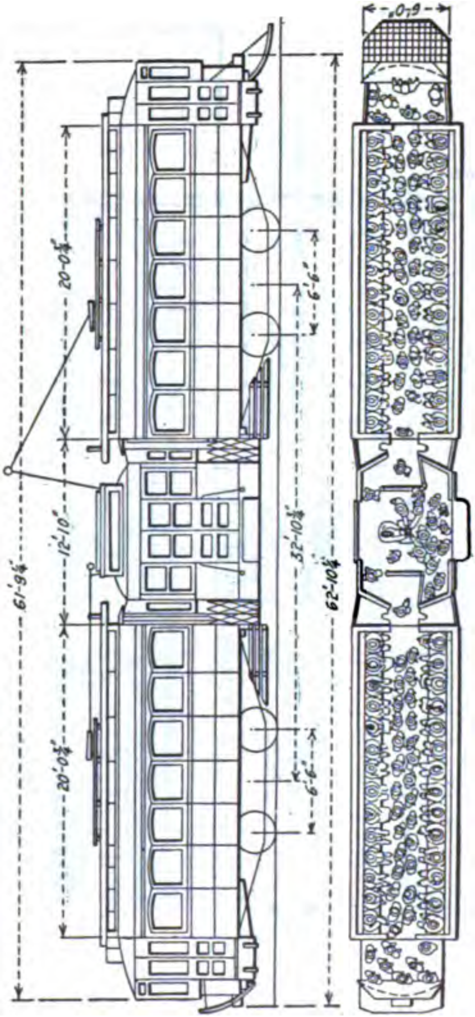
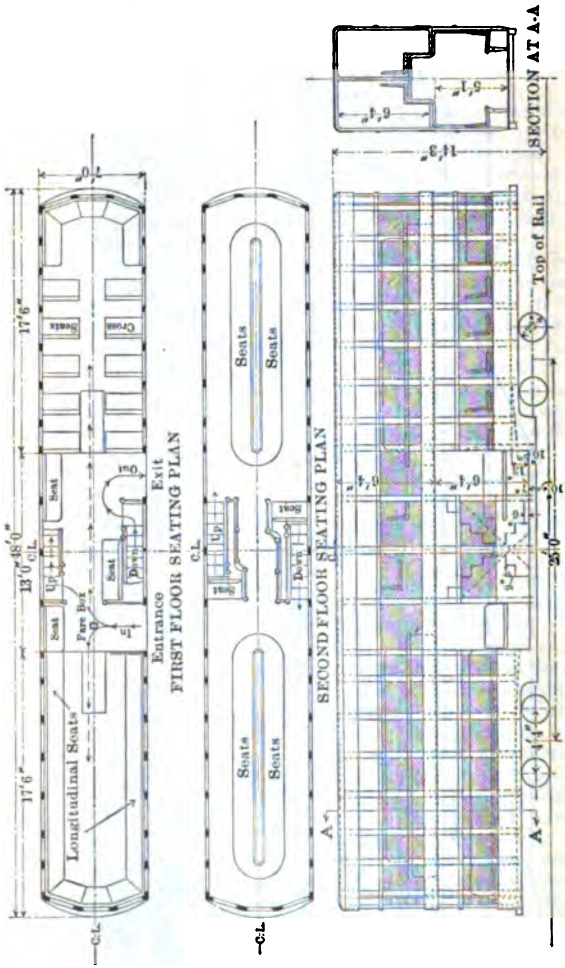


FIG. 21.—Boston articulated car.



SIDE ELEVATION

FIG. 22.—Pittsburgh double deck, double door car.

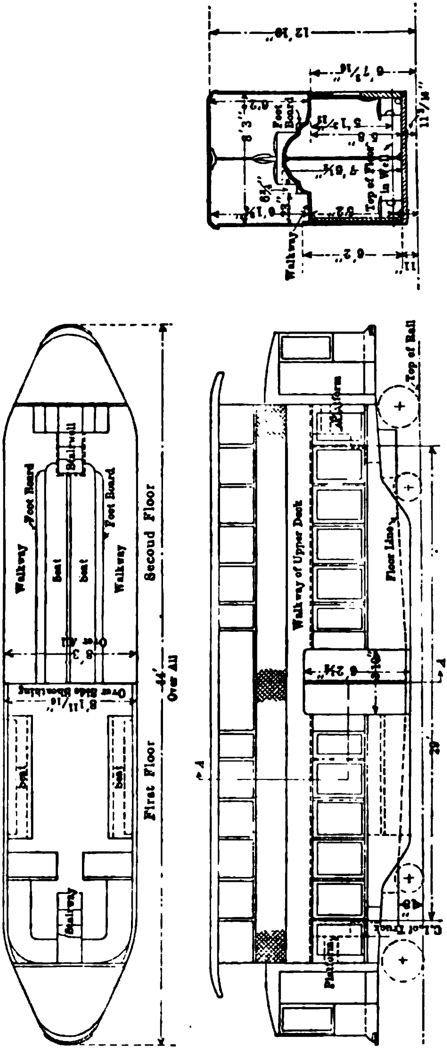


FIG. 23.—New York double deck car.

ESTIMATE OF COST AND EFFICIENCY OF VARIOUS TYPES OF OPERATING UNITS

	Double deck car	Single motor car	2 motor cars equipped with multiple-unit control	1 motor lead car and 1 motor trailer	1 motor lead car, 1 trailer, stepless convertible
Cost of equipment (est.).	$6,500.00	$4,902.52	$9,932.98	$8,773.44	$7,202.52
Depreciation per year, 8 per cent.	520.00	392.20	794.64	701.87	576.20
Interest on investment per year, 6 per cent.	390.00	294.15	595.98	526.40	432.15
Taxes per year at $1.50 per 1000.	97.50	73.54	148.99	131.60	108.04
Insurance per year at $7.50 per 1000.	48.75	36.77	74.50	65.80	54.02
Average yearly car mileage.	47,254	47,254	47,254	47,254	47,254
Seated passengers....	88	40	80	80	100
Seating and standing passengers.	171	100	200	200	210
Total weight without passenger load, lb.	46,000	35,773	71,546	68,209	61,773
* Depreciation.......	1.100	0.830	1.681	1.485	1.219
* Interest on investment.	0.825	0.622	1.261	1.114	0.914
* Taxes.............	0.206	0.155	0.315	0.278	0.228
* Insurance..........	0.103	0.078	0.157	0.139	0.114
* Cost of energy.....	1.602	1.144	2.288	2.038	1.976
* Maintenance.......	2.058	1.470	2.940	2.940	2.940
* Wages, conductors and motormen.	5.227	5.227	7.841	7.841	7.841
Total cost, cents per train mile.	11.121	9.526	16.483	15.835	15.232
Cents per passenger capacity per train mile.	0.0650	0.0952	0.0824	0.0792	0.0725

* Per train mile, cents.

Selection of the double deck car was also influenced by these economic features: Additional safety to passengers by elimination of dangers incident to entrance and exit; greater convenience in entering and leaving car; improvement in working conditions of motormen and conductors; better sanitation through scientific ventilation; elimination of dangers due to premature starting of cars, since they cannot start until the doors have been shut; greater facilities for passengers who desire to smoke; traffic congestion reduced by increase of almost 100 per cent. in the carrying capacity per foot of street occupied; decreased maintenance and operating expenses in the handling of passengers.

Storage Battery Cars. In the development of the storage battery car the effort has been directed toward securing a large daily mileage at a reasonable cost per mile, or, in other words, to reduce the ampere-hour input per car mile. This has been done by decreasing the weight of the storage equipment, decreasing the weight of car body and trucks, and by increasing the efficiency of batteries and motors, and a mileage of from 50 to 100 miles can be secured in a 12-hour day without re-charging. There are at present nearly 200 storage battery cars in operation in New York City, this being perhaps 70 per cent. of the total number in operation in this country. At the present state of development of the storage battery car, this type of car cannot be considered in locations where traffic is dense, when the service is severe as regards high schedule speed, or when long continuous grades are met. In service such as that in New York City where trolleys or other types of self-propelled cars cannot for one reason or another be used, such conditions are best met by the storage battery car. The cars rarely exceed 20 miles per hour free running speed and in consequence bodies and trucks can be built very light, resulting in cars which weigh, complete, little if any more per passenger seat than ordinary trolley cars. Fig. 24 shows a type in service on the New

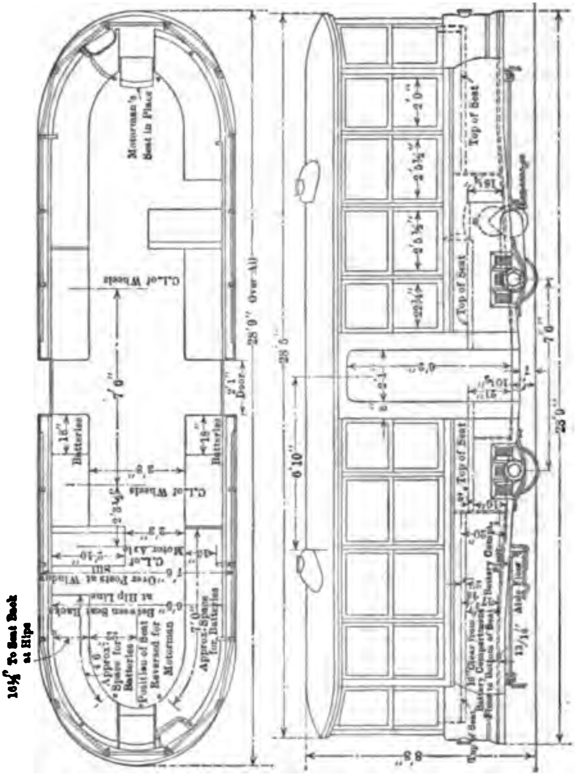


FIG. 24.—Center entrance low floor storage battery car, New York.

York Railways, the general dimensions and weights of which are as follows:

Length over all	28 ft. 9 in.
Height over roof	8 ft. 8 in.
Width at sills	6 ft. 7 in.
Greatest width at belt rails	7 ft. 9¼ in.
Wheel base of single truck	7 ft. 6 in.
Slope of ramp in floor	6 in. in 8 ft. 6 in.
Diameter of wheels	21 in.
Height of step from street	10 in.
Seating capacity	34 17-in. seats.
Weight of car complete	16,500 lb.
Weight of battery	4,300 lb.
Weight of car without battery	12,200 lb.

As indicated in the figure, each of the two motors rests on the bottom framing of the car and under a cross seat. Its pinion meshes with a gear on a back gear shaft which drives the car axle by sprocket wheel and chain.

General operating data on the storage battery cars of the Third Avenue Railway, New York, are given as follows:

OPERATING DATA ON STORAGE BATTERY CARS OF THE THIRD AVENUE RAILWAY, NEW YORK

Length of run, minimum	5 miles
Length of run, maximum	10 miles
Length of run, average	8 miles
Maximum grades	5 per cent.
Average number of miles per car a day	58
Number of trips per day, minimum	7
Number of trips, per day maximum	18
Number of trips per day, average	10
Maximum speed	15 m.p.h.
Schedule speed, minimum	6 m.p.h.
Schedule speed, maximum	7.6 m.p.h.
Average number of stops per mile	8
Average duration of stops	6 seconds.
Number and type of cars operated (of one type).	121[*]
Weight of car complete	14,500 lb.
Length of car	26 ft. 1½ in.
Seating capacity	26
Number of motors per car, type and rating—two motors, rated 30 amp. at 110 volts.	
Kind of battery and number per car, 58-cell, 29-plate lead battery.	
Kw-hr. per car mile used at motors	0.5 to 0.6
Kw-hr. per car mile purchased, a.c. energy at 6600 volts	1 to 1.2
Kw-hr. per car mile battery input	0.910
Amp-hr. per car mile of charge	5.53 to 6.85
Amp-hr. per car mile of discharge	4.52 to 5.45
Amp-hr. efficiency of battery	82 per cent.
Voltage efficiency of battery	79.1 per cent.
Watt-hour efficiency of battery	64.8 per cent.
Time required to charge batteries	7½ to 9 hours
Number of miles obtained per charge, normal	85 miles
Number of miles obtained per charge, maximum	119 miles
Operating Cost per Car Mile:	
Platform expenses	8.75 cents
Total repairs to cars, trucks, electrical equipment and all shop and carhouse expense	2.55 cents
Power	1.2 cents

Rapid Transit Cars. In the design of a car for elevated and subway service the conditions to be met are considerably different from those encountered by a car on a street railway, both as to the limitations of size and the difficulties of traffic to be handled. The design will also differ from that of the rolling stock of a steam or electrified suburban line, in which service a higher ratio of seating to passenger capacity must be given than on the shorter run city high-speed lines. On most subway and elevated lines it is almost physically impossible to seat all rush-hour passengers throughout the trip even with a maximum length of train and the shortest possible headway. Since the rapid transit line cannot

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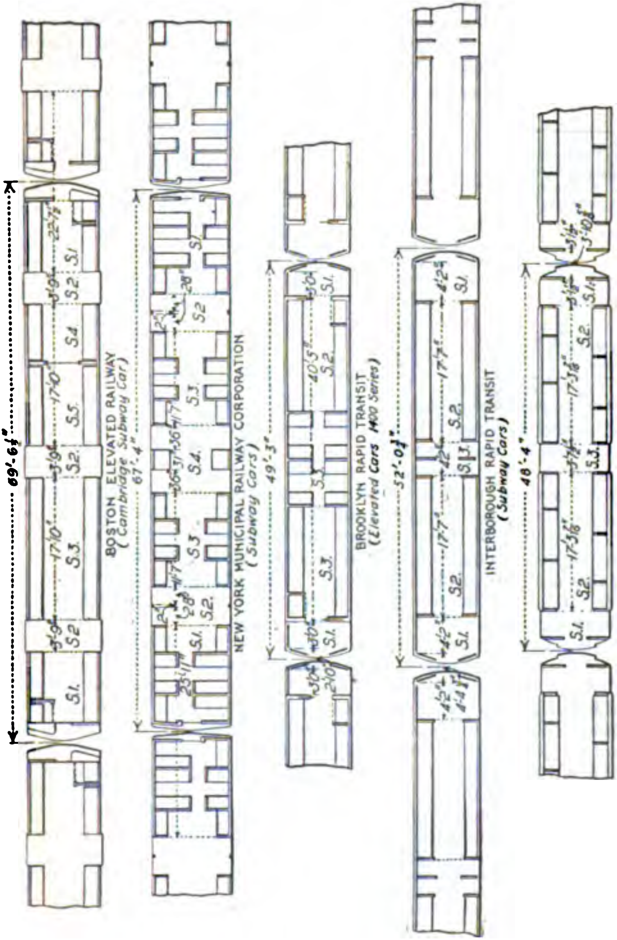
[*] Now 160 cars.



FIGS. 25-29.—Typical rapid transit cars.

supply seats to all of the rush-hour passengers, an arrangement must be made which will provide maximum standing and seating room for the heavy and light hours, respectively. Figs. 25 to 29, inclusive, show typical floor plans with door and seating layouts of various leading types of city rapid transit cars, and the tables on pp. 545 to 549, inclusive, give various data relative to the weights, capacity, motor equipment, etc., of these cars. The following table shows comparative costs of these cars:

COMPARATIVE COSTS—VARIOUS STEEL PASSENGER CARS

Type of car (identity of six companies withheld)	Total cost completely equipped	Cost per passenger seat	Cost per passenger capacity seated and standing	Cost per lineal foot
A	$12,236.97	$169.95	$46.00	$175.98
B	18,500.00	260.56	99.46	287.09
C	13,000.00	250.00	84.41	253.25
D	14,500.00	329.54	93.54	300.00
E	12,500.00	284.09	80.64	258.62
F	14,000.00	318.18	76.92	268.91
New York Municipal.	15,000.00 (estimated)	166.66[1]	55.55[2]	223.88

[1] On basis of 90 seats.
[2] On basis of 270 passengers.

Interurban Cars. In the design of interurban cars it is usually desirable for the comfort of the passenger on the longer trips to provide a full equipment of cross seats. It is generally deemed desirable also to provide a separate smoking compartment and also a compartment for baggage and light express matter, the necessity or desirability of these compartments becoming greater as the headway becomes longer and the distance between terminals greater. It is also desirable on long runs, and in some states, compulsory, that toilet facilities be provided. The usual layout for such a car is shown in general by Fig. 30, p.. 550, which shows the plan of the all-steel cars which are being used by the Union Traction Company of Indiana. Such cars are usually made single ended with the baggage compartment in front. This position affords an additional factor of safety in case of accident and allows the motorman to attend to loading and unloading baggage at the station stops. In the car shown, all partitions were installed with large glass areas, which arrangement permits the conductor to remain on the rear platform from which position he can observe the movements of the motorman and see all passengers in the car. The general dimensions and weights of the car shown are as follows:

Length over bumpers	61 ft.
Width over side plates	8 ft. ½ in.
Height from rail to bottom of sill	43 in.
Height from bottom of sill to top of roof	9 ft.
Truck centers	38 ft. 4 in.
Weight of car body with electrical and air-brake apparatus.	45,200 lb.
Weight of two standard trucks complete with four motors.	40,400 lb.
Weight of car body fully equipped and mounted on trucks.	85,600 lb.

TABLE OF COMPARATIVE DATA FOR VARIOUS ELEVATED AND SUBWAY CARS

Road and class of service	Number of cars in train			Total length over couplers (Note 1)		Total capacity				Horse-power (Note 2)						
						Seated				Per ton		Per passenger seat				
	Motor	Trailer	Total	Ft.	In.	Min. (rush hour)	Med. (med. traffic)	Max. (light traffic)	Max. (seated and standing)	Light	Loaded max. capacity (seated and standing)	Rush hour service (min. seating)	Med. traffic (med. seating)	Light traffic (max. seating)	Per max. pass. capacity (seated and standing)	Total per train
Interborough Rapid Transit Subway—Latest steel cars.	1	0	1	52	0¾	44	46	48	169	10.27	7.88	9.09	8.70	8.33	2.37	400
	.	1	1	52	0¾	44	46	48	169	.....	....	.....	.....	.....	....	.....
	2	0	2	104	1½	88	92	96	338	10.27	7.88	9.09	8.70	8.33	2.37	800
	2	1	3	156	2¼	132	138	144	507	7.73	5.75	6.06	5.80	5.55	1.58	800
	3	2	5	260	3¾	220	230	240	845	7.13	5.28	5.45	5.22	5.00	1.42	1200
	4	2	6	312	4½	264	276	288	1014	7.73	5.75	6.06	5.80	5.55	1.58	1600
	5	3	8	416	6	352	368	384	1352	7.35	5.46	5.68	5.43	5.21	1.48	2000
	7	3	10	520	7½	440	460	480	1690	8.02	5.98	6.36	6.08	5.83	1.66	2800
New York Municipal Railway Corporation—Subway.	1	0	1	67	3	78	......	90	270	6.6	4.5	3.3	......	3.1	1.04	280
	2	0	2	134	6	156	......	180	540							560
	3	0	3	201	9	234	......	270	810							840
	4	0	4	269	0	312	......	360	1080							1120
	5	0	5	336	3	390	......	450	1350							1400
	6	0	6	403	6	468	......	540	1620							1680
	7	0	7	470	9	546	......	630	1890							1960
	8	0	8	538	0	624	......	720	2160							2240
Brooklyn Rapid Transit—Elevated, series motor car and standard trailer.	1	0	1	49	3		50		154	11.15	8.58		8.0		2.59	400
	.	1	1	48	0		48		148	.....	....		....		....	....
	2	0	2	98	6		100		308	11.15	8.58		8.0		2.59	800
	2	1	3	146	6		148		456	9.01	6.62		5.41		1.75	800
	3	1	4	195	9		198		610	9.62	7.16		6.07		1.97	1200
	3	2	5	243	9		246		758	8.46	6.15		4.88		1.58	1200
	4	2	6	293	0		296		912	9.0	6.62		5.41		1.75	1600

For notes, see p. 547.

TABLE OF COMPARATIVE DATA FOR VARIOUS ELEVATED AND SUBWAY CARS.—(*Continued*)

Road and class of service	Number of cars in train			Total length over couplers (Note 1)		Total capacity				Horse-power (Note 2)						
						Seated				Per ton		Per passenger seat				
	Motor	Trailer	Total	Ft.	In.	Min. (rush hour)	Med. (med. traffic)	Max. (light traffic)	Max. (seated and standing)	Light	Loaded max. capacity (seated and standing)	Rush hour service (min. seating)	Med. traffic (med. seating)	Light traffic (max. seating)	Per max. pass. capacity (seated and standing)	Total per train
Boston—Cambridge subway.	1	0	1	69	6½		72		266	9.3	6.50		5.55		1.50	400
	2	0	2	139	1		144		532							800
	3	0	3	208	7½		216		798							1200
	4	0	4	278	2		288		1064							1600
	5	0	5	347	8½		360		1330							2000
	6	0	6	417	3		432		1596							2400
	7	0	7	486	9½		504		1862							2800
	8	0	8	556	4		576		2128							3200
Hudson & Manhattan—Original type. Tunnel service.	1	0	1	48	4		44		158	8.64	6.65		7.27		2.02	320
	2	0	2	96	8		88		316							640
	3	0	3	145	0		132		474							960
	4	0	4	193	4		176		632							1280
	5	0	5	241	8		220		790							1600
	6	0	6	290	0		264		948							1920
	7	0	7	338	4		308		1106							2240
				386	4		352		1264							2560
Hudson & Manhattan—New Penusylvania Newark service.	1	0	1	48	4		44		158	12.33	9.46		10.2		2.85	450
	2	0	2	96	8		88		316							900
	3	0	3	145	0		132		474							1350
	4	0	4	193	4		176		632							1800
	5	0	5	241	8		220		790							2250
	6	0	6	290	0		264		948							2700
	7	0	7	338	4		308		1106							3150
	8	0	8	386	8		352		1264							3600

For note, see p. 547.

Table of Comparative Data for Various Elevated and Subway Cars.—(*Continued*)

Road and class of service	Number of cars in train			Total length over couplers (Note 1)		Total capacity				Horse-power (Note 2)						
						Seated			Max. (seated and standing)	Per ton		Per passenger seat			Per max. pass. capacity (seated and standing)	Total per train
	Motor	Trailer	Total	Ft.	In.	Min. (rush hour)	Med. (med. traffic)	Max. (light traffic)		Light	Loaded max. capacity (seated and standing)	Rush hour service (min. seating	Med. traffic (med. seating)	Light traffic (max. seating)		
Long Island Railroad Subway—Suburban Flatbush avenue division.	1	0	1	51	4		52		154	10.05	7.91		7.7		2.59	400
	.	1	1	46	6		56		136	.....	....		....		....	....
	2	0	2	102	8		104		308	10.05	7.91		7.7		2.59	800
	2	1	3	149	2		160		444	8.04	6.12		5.0		1.80	800
	3	1	4	200	6		212		598	8.62	6.64		5.66		2.01	1200
	3	2	5	247	0		268		734	7.54	5.70		4.48		1.63	1200
Long Island Railroad Subway—Suburban Pennsylvania station.	1	0	1	64	5¼		71		186	9.0	7.21		6.62		2.52	470
	2	0	2	128	10½		142		372							940
	3	0	3	193	3¾		213		558							1410
	4	0	4	257	9		284		744							1880
	5	0	5	322	2¼		355		930							2350
	6	0	6	386	7½		426		1116							2820
	7	0	7	451	0¾		497		1302							3290
	8	0	8	515	6		568		1488							3760

Note 1: Projection of couplers beyond buffers in case of Brooklyn Rapid Transit, Boston, and Hudson & Manhattan, assumed to be 2 in., and for New York Municipal Railway 1½ in. Note 2: The horse-power per car of New York Municipal Railway Corporation proposed subway cars, 280 h.p. Note 3: The weight of each passenger assumed to be 140 lb. Note 4: Standing capacity figured at 1½ sq. ft. per passenger, allowing 9 in. at longitudinal seats for knee room. Note 5: No deduction made for motorman's cab in calculating passenger capacity.

TABLE OF COMPARATIVE DATA FOR VARIOUS ELEVATED AND SUBWAY CARS.—(*Continued*)

Road and class of service	Weight in pounds							Per cent. weight on drivers	
	Total		Per foot of train (light)	Per passenger seat light			Per max. pass. capacity (seated and standing)		
	Light	With max. pass. load (seated and standing)		Rush hour service (min. seating)	Med. traffic (med. seating)	Light traffic (max. seating)		Light	Loaded (max. capacity)
Interborough Rapid Transit Subway—Latest steel cars.	77,870	101,530	1496	1769	1693	1622	460	59.5	57.3
	51,410	75,070	987	1168	1118	1071	304	......	....
	155,740	203,060	1496	1769	1693	1622	460	59.5	57.3
	207,150	278,130	1324	1568	1500	1439	408	44.8	41.8
	336,430	454,730	1292	1529	1462	1403	398	41.4	38.3
	414,300	556,260	1324	1568	1500	1439	408	44.8	41.8
	543,580	732,860	1305	1543	1476	1416	402	42.6	39.7
	699,320	935,920	1343	1589	1520	1457	414	46.4	43.5
New York Municipal Railway Corporation—Subway.	85,000	122,800	1268	1089	....	944	315	50.1	49.9
	170,000	245,600							
	255,000	368,400							
	340,000	491,200							
	425,000	614,000							
	510,000	736,800							
	595,000	859,600							
	680,000	982,400							
Brooklyn Rapid Transit—Elevated, series motor car and standard trailer.	71,660	93,220	1455		1433		465	60.4	57.9
	34,500	55,220	719		719		233	......	....
	143,320	186,440	1455		1433		465	60.4	57.9
	177,820	241,660	1213		1200		390	48.6	44.7
	249,480	334,880	1274		1260		409	51.8	48.4
	283,980	390,100	1164		1153		375	45.6	41.6
	355,640	483,320	1213		1200		390	48.6	44.7
Boston—Cambridge Subway.....	85,900	123,140	1235		1193		323	58.0	55.6
	171,800	246,280							
	257,700	369,420							
	343,600	492,560							
	429,500	615,700							
	515,400	738,840							
	601,300	861,980							
	687,200	985,120							

See notes on page 547.

TABLE OF COMPARATIVE DATA FOR VARIOUS ELEVATED AND SUBWAY CARS.—(*Continued*)

Road and class of service	Weight in pounds							Per cent. weight on drivers	
	Total		Per foot of train (light)	Per passenger seat light			Per max. pass. capacity (seated and standing		
	Light	With max. pass. load (seated and standing)		Rush hour service (min. seating)	Med. traffic (med. seating)	Light traffic (max. seating)		Light	Loaded (max. capacity)
Hudson & Manhattan—Original type. Tunnel service.	74,100	96,220	1533		1684		469	56.4	54.9
	148,200	192,440							
	222,300	288,660							
	296,400	384,880							
	370,500	481,100							
	444,600	577,320							
	518,700	673,540							
	592,800	769,760							
Hudson & Manhattan—New Pennsylvania Newark service.	73,000	95,120	1510		1658		462	54.1	53.1
	146,000	190,240							
	219,000	285,360							
	292,000	380,480							
	365,000	475,600							
	438,000	570,720							
	511,000	665,840							
	584,000	760,960							
Long Island Railroad Subway—Suburban Flatbush Avenue division.	79,564	101,124	1550		1530		516	61.0	58.6
	40,000	59,040	860		715		294	......	....
	159,128	202,248	1550		1530		516	61.0	58.6
	199,128	261,288	1335		1245		448	48.7	45.4
	278,692	362,412	1390		1315		466	52.2	49.2
	318,692	421,452	1290		1190		434	45.6	42.2
Long Island Railroad Subway—Suburban Pennsylvania station.	104,400	130,440	1620		1470		562	58.7	56.4
	208,800	260,880							
	313,200	391,320							
	417,600	521,760							
	522,000	652,200							
	626,400	782,640							
	730,800	913,080							

The Joint Committee on Transportation Engineering, A E.R.E.A., 1914, found that when considered with regard to entrances there are eight different general styles of interurban cars designed for train operation. These are shown by Fig. 31. *a* to *e*, inclusive, are the most common types; *a*, *b*, and *c* are double-end and the rest are single-end cars. Where there is any possibility of train operation, end doors should be provided. Swing doors are preferable to sliding doors for all but the baggage compartment because they allow more rigid and strong bulkhead construction, cause less trouble and have a lower maintenance cost

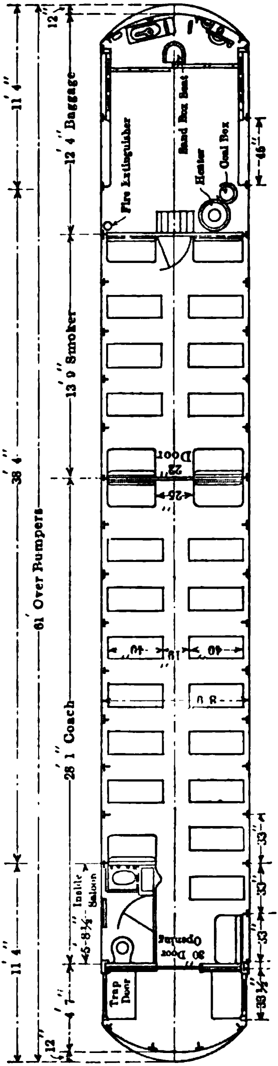


FIG. 30.—Typical all-steel interurban car, Union Traction of Indiana.

Freight and Express Cars. Where shipments are made in less than carload lots there should be two large doors on each side of the car. Fig. 32 (from the report of the above committee) shows typical outline plans for freight and express cars. Cars *a*, *b* and *c* are motor cars and the rest are shorter designs for trailers. Car *a*, having one large and one small door on each side, is satisfactory when the car is not so long that time is lost in carrying freight between door and end of car. In *b* the small end doors facilitate the handling of long pieces of freight. Car *c* affords the most rapid handling of freight. In *d*, *e* and *f* the corner doors permit passage between cars. Car *f* is provided with an end door for the handling of automobiles and other bulky freight.

Standard Dimensions of Cars. The A.E.R.E.A. standard height of couplers for city cars, measured from the top of the rail to the center of the coupler, is 20 in. The standard height of platform, measured from the top of rail to the top of platform floor, is

31 in. for city cars and 51 in. for interurban cars. The standard height of city car bumpers, measured from the top of the rail to the top of bumper, is 31 in., and the width of bumper is 6 in.

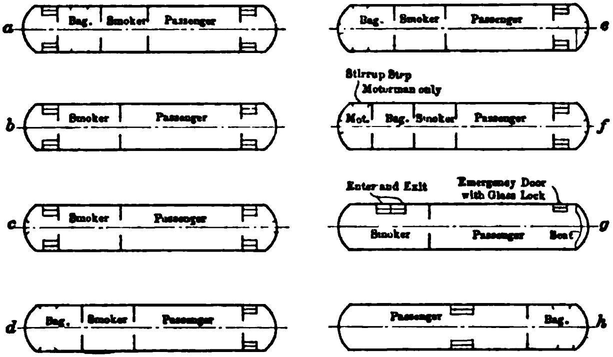


Fig. 31.—Outline plans for interurban passenger cars.

Where possible, the top of the bumper should be reinforced with a bumper casting of suitable design, which will engage the bumper of interurban cars as well as provide a wider surface, thus preventing the bumpers from passing over each other and the cars from telescoping in case of collision between city and interurban cars. This bumper casting should be designed to include the pocket casting for coupling city cars to interurban cars, as later referred to. The standard height of interurban car bumper, measured from the top of rail to the top of bumper, is 51 in., and the width of bumper is 8 in. The bumper arrangement on interurban cars should be made as solid and substantial as the design of the equipment will permit, and a suitable arrangement should be made to prevent the bumper of the interurban cars from passing over the bumper of the lower city cars. Figs. 33 and 34 show the above standard dimensions.

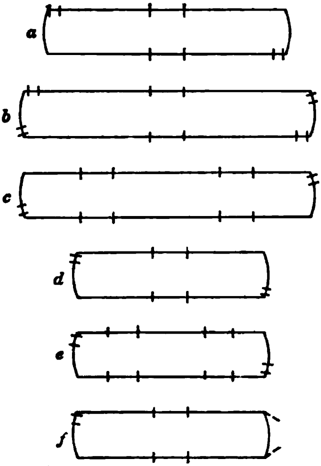


Fig. 32.—Outline plans for freight and express cars.

Height of Car Steps. Public authorities have recently made a number of regulations relative to the height of steps. For instance, the Massachusetts Public Service Commission in 1914 ordered that all passenger cars purchased thereafter by street railway companies shall be equipped with steps not over 15 in. in height, the bottom steps to be measured from a plane even with the top of the rails, also that all cars then owned and operated by street railway companies should be altered prior to July, 1915, so that no step should be more than 17 in. in height.

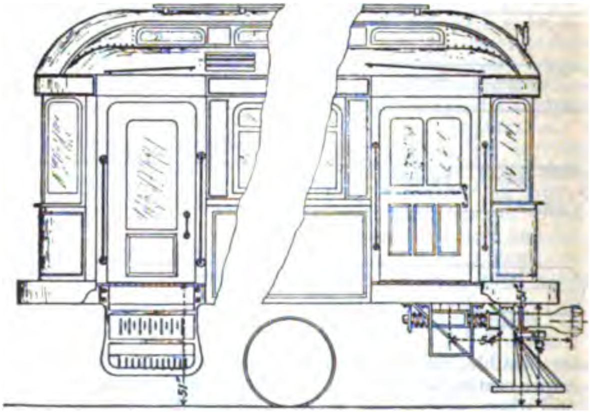

INTERURBAN CAR

FIG. 33.—A.E.R.E.A. standard dimensions, interurban car.

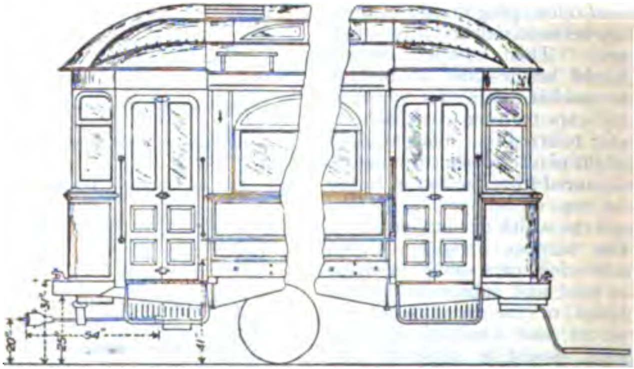

CITY CAR

FIG. 34.—A.E.R.E.A. standard dimensions, city car.

From many tests on interurban cars the Joint Committee on Transportation Engineering, A.E.R.E.A., 1914, found that the time required for boarding and alighting was less with a step arrangement having four than with one having three rises. The tests showed that for three rises consisting of a 16½-in. rise from the rail to the first tread, then two 14-in. rises to the vestibule platform, the average boarding time was approximately 3 seconds and the average alighting time was 2½ seconds. For four rises consisting of a 15-in. rise from the rail to the first tread, then three 10-in. rises to the vestibule platform, the average boarding and alighting times were alike, being approximately 1¾ seconds.

Automatic Couplers and Radial Draft Rigging. There has been adopted as standard by the A.E.R.E.A. for use on interurban cars a coupler of the vertical plane type which has the same contour lines of knuckle and guard arm as, and which will automatically couple with, standard steam railroad couplers of the M.C.B. type. The draft rigging and draw-bar supports for these couplers should be such that, with sudden changes in grade, the vertical displacement of the couplers with reference to each other will not be sufficient to cause the knuckles to become disengaged. The length of the radial coupler, measured from the center of the pocket-pin to the pulling face, should be 54 in. This length will apply to both interurban cars and to cars in city service. On city cars, where the bumper arrangements will permit, a pocket casting is to be placed on the top of the bumper, the center of the pocket to be 35 in. above the top of the rail, and the casting to be of ample strength and properly braced, so that by means of a suitable bar city cars may be coupled on a level with the automatic couplers of interurban cars. For this purpose it is advisable at present to maintain a link slot and coupling pin hole in the knuckle of the automatic couplers. The following are the A.E.R.E.A. standard specifications for couplers for interurban cars where the interchange of equipment is involved:

1. All couplers must be made to automatically couple by impact, and to uncouple without the necessity of going between the cars, with M.C.B. and all other types of M.C.B. contour couplers, whether used by steam or electric roads.
2. A device should be adopted for holding couplers on center within the required limits when inter-coupling with steam railroads.
3. An open knuckle for shackle bar connection should be used.
4. The draft gear, where possible, should meet M.C.B. requirements, and the draw-bar anchorages should be equivalent in strength to M.C.B. equipment and requirements.
5. Couplers must not uncouple when cars are being pushed around a curve of 35-ft. center radius.
6. There should be an arrangement to release and open the knuckle without requiring the operator to pass between the cars.
7. The face of the knuckle vertically should be 16 in. maximum.
8. The height of the draw-bar center should be 31½ in. minimum and 34½ in. maximum above the head of the rail.
9. The coupling center of couplers must have a minimum projection of 6 in. beyond buffer faces at any point between the working limits of couplers.

10. Couplers should be placed on both ends of the cars.

The contour line for automatic couplers adopted as standard by the Master Car Builders' Association is shown by Fig. 35.

End Connections on Interurban Cars Engaged in the Interchange of Cars. The locations of the various end connections for interurban cars, adopted as recommended practice of the A.E.R.E.A., are shown in Fig. 36. In this figure the locations shown of control train and bus line electropneumatic and trailer light receptacles are such as to clear end doors where these are employed in the event conditions permit; if it is otherwise required, their position may be altered, but the re-location should be on the vertical center, as shown. The receptacles indicated by dotted lines are optional when not required; the trailer light receptacles are optional when bus lines are used. The headlight receptacle and bracket and trolley retriever bracket are optional when not required.

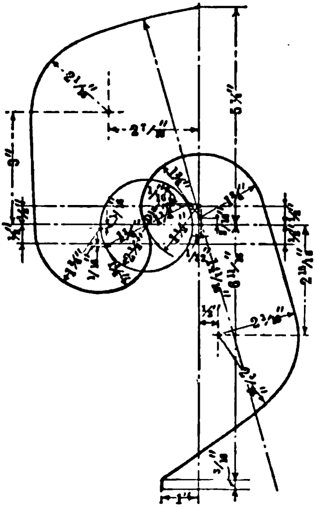


FIG. 35.—Contour line, M.C.B. standard coupler.

The Standardization Committee of the Central Electric Railway Association has proposed a standard location of electropneumatic signal whistles and wiring, as shown by Fig. 37, and also a standard trailer light connector, as shown by Fig. 38.

Coupler with Wire and Air Connections. In some instances, couplers have been arranged so that the one operation of coupling the cars also makes connections for the air, lights and signals. Fig. 39 shows the home-made addition to a car coupler, as made by the United Railways of St. Louis, for carrying contacts for signal and lighting circuits.

Train Operation. The full realization of the advantages of multiple-unit operation can be obtained only on roads having ample substation capacity and a liberal feeder system, although the requirements of these items can be kept within very reasonable limits by the proper training of the motorman. Where multiple-unit trains are employed, it is usually not necessary to have either cars or equipment as large as if they were operated singly at all times. The predecessor and principal competitor of the multiple-unit train is the combination of the motor car and trailer. If the motors are of sufficient capacity, and especially if two-car trains are to be operated for only short periods of time, trailer operation may be more economical than multiple-unit operation. Care should be taken that in such operation the motors are not overloaded since the excessive heating may do them damage. The effect on motors of pulling a trailer may be seen from the curves in Figs. 40 and 41 which are reproduced from a paper by Mr. Clarence Renshaw, Trans. A.I.E.E., 1903. Fig. 40 showing rise in temperature of motors with one car operating singly and Fig. 41 showing the rise in temperature with the car hauling a trailer during the rush hours. It will be noted that the presence of the trailer for one trip in the morning when the motors were fairly cool

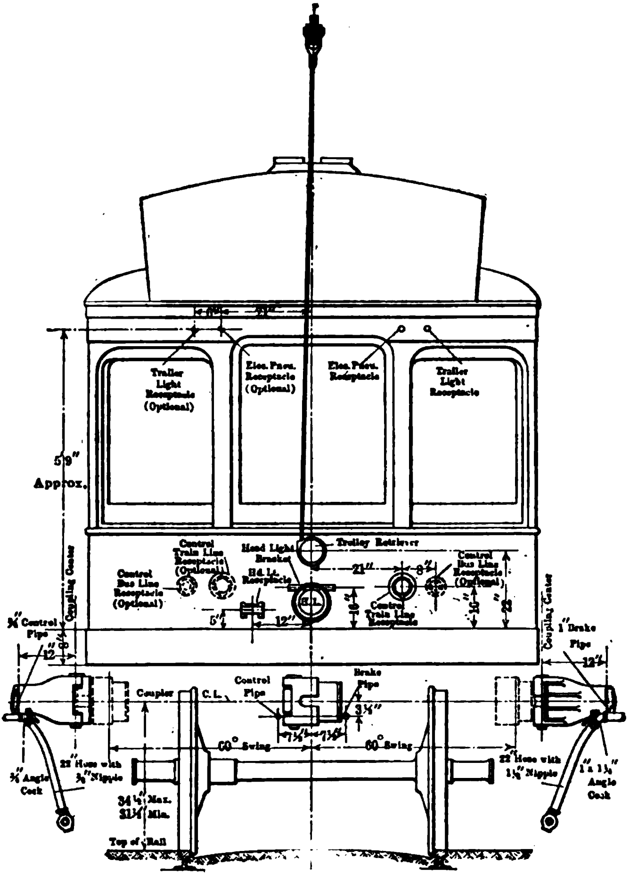
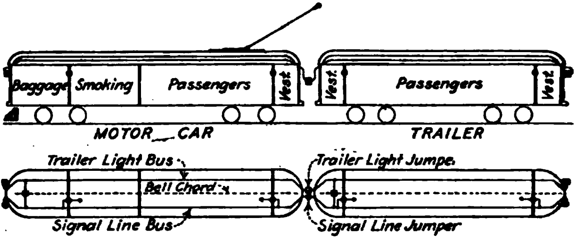


FIG. 36.—A.E.R.E.A. recommended location of end connections for interurban cars.

only caused the temperature to rise much more rapidly without causing it to reach any higher value, but in the afternoon when the motors had reached the temperature where they would otherwise have remained, the addition of a trailer for about 1¾ hours raised the temperature in this case approximately 25 deg. from 75 deg. C. The use of trailers for rush-hour service is also likely to cause delay, due to the reduction in speed on account of the added weight, and the inability of the trailer to move by itself causes further delay in backing it up, dropping it, and possibly shifting it at stub-end terminals. Otherwise, in certain classes of service the trailer operation may be very successful without causing injury to the motor equipment, especially by taking advantage of the thermal capacity of the motors in attaching trailers to motor cars which have been out of service for 5 or 6 hours and leaving them attached for only a limited number of trips.



- ● *Signals, with necessary resistance, to be located so as to be audible on both sides of bulkheads.*
- ● *Signal line connectors, as per print No. B-11-A.*
- ▣ *Trailer light connectors, as per print No. C-5-A, used for light heater and other auxiliary circuits.*
- ■ *Signal sws. operated by bell cord and connecting trailer light with signal line bus.*

FIG. 37.—C.E.R.A. standard location of signal whistles and wiring.

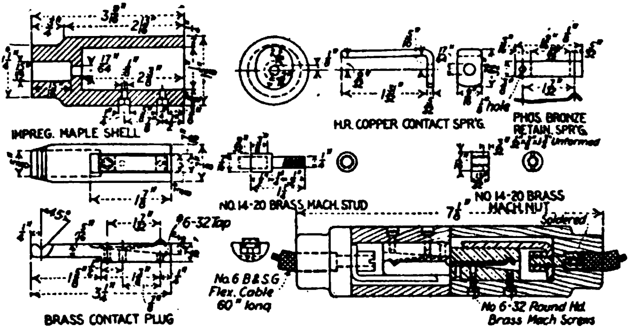

IMPREG. MAPLE SHELL
H.R. COPPER CONTACT SPR'G
PHOS. BRONZE RETAIN. SPR'G
Unformed
hole
NO. 14-20 BRASS MACH. STUD
NO. 14-20 BRASS MACH. NUT
Soldered
#6-32 Tap
No. 6 B&S G. Flex. Cable 60" long
No. 6-32 Round Hd. Brass Mach. Screws
BRASS CONTACT PLUG

FIG. 38.—C.E.R.A. standard trailer light connector.

It may be possible, also, to compensate for the extra load by a reduction in the number of stops which would ordinarily be made by the motor car without the trailer. With multiple-unit operation it is of course possible to apply motors to the cars more efficiently, both as to size and gear ratio, than if trailer operation had to be provided for, but on the other hand, the motor equipment on all cars, including those used as the second car, represents considerable dead investment when train operation is resorted to only infrequently. In rapid transit service where train operation is the rule instead of the exception, there is of course no question as to

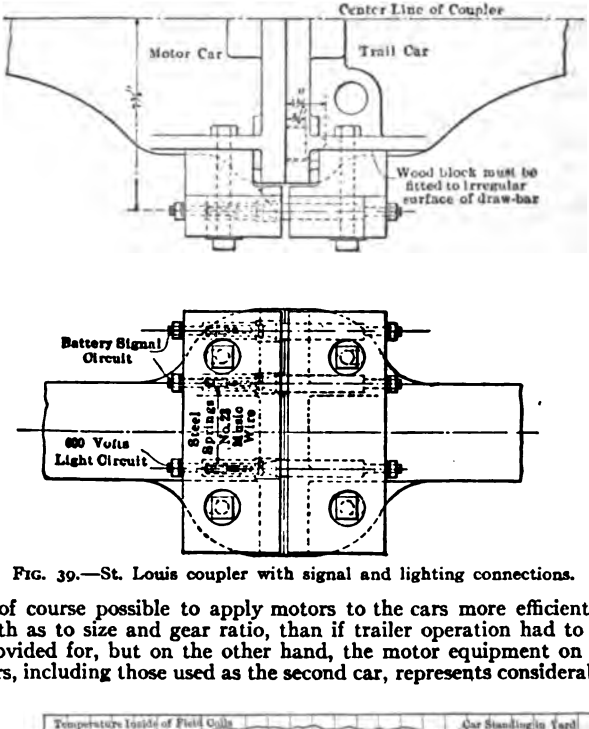


FIG. 39.—St. Louis coupler with signal and lighting connections.

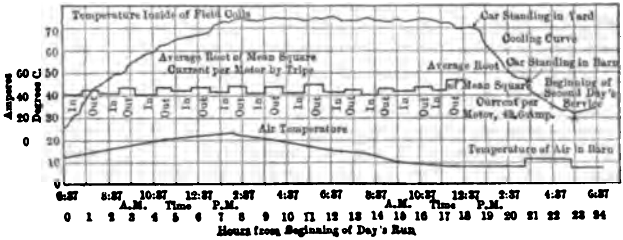


FIG. 40.—Motor temperature, single car.

the advantage of multiple-unit operation, thus distributing the motors among the axles all along the train, reducing the capacity of the single-motor equipments, and making available for traction a much greater proportion or all of the weight of the entire train.

The Public Service Railway Company of New Jersey recently conducted a series of experiments with the view of determining the merits of multiple-unit train operation as applied to city service; whether the operation of two-car trains in city service was economical and desirable; and the combination and number of motors best suited for such operation. Comparative tests were made with six trains, the following description being taken from Aera, 1913: The trains tested comprised two single cars, one four-motor and one two-motor, one train of two four-motor cars, one train of one four-motor and one two-motor cars, one train of two two-motor cars and one train of a four-motor car and trailer. Motors were Westinghouse No. 307, with HL control. Some of the operating results are as follows:

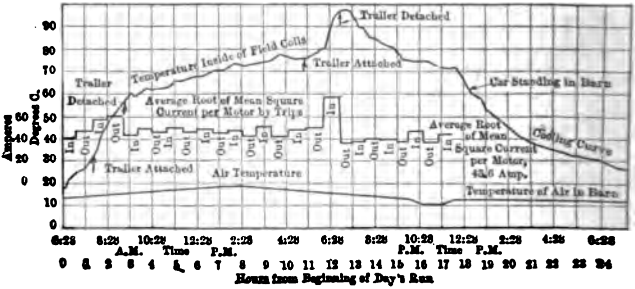


Fig. 41.—Motor temperature, with rush hour trailer.

Class of train	Per cent. of standard running time	Kilowatts per car mile, per cent.	Watt-hours per ton mile, per cent.
Four-motor single car	101.4	100.0	100.0
Two-motor single car	106.5	68.4	78.7
Two four-motor cars	100.8	96.0	100.0
One four-motor and one two-motor car.	102.9	81.5	92.6
Two two-motor cars	104.5	65.9	83.5
Four-motor car and trailer	117.8	94.1	111.2

The above shows that the four-motor cars, either single or in trains, kept fairly close to the standard running time. A train made up of a four-motor car and a two-motor car lost a little time, but not as much as the two-motor cars, either single or connected. The four-motor car with trailer fell much further behind. The energy consumption figures are taken from typical rush-hour trips in the direction of travel, and it will be noted that the two-motor cars show a saving of about 30 per cent. in energy consumption per car mile over the four-motor cars. This, because of the lighter weight of the two-motor cars, corresponds to about 20 per cent. per ton mile. The six-motor train shows a saving of about 14 per cent. per car mile, or about 8 per cent. per ton mile, as compared with the eight-motor train. The motor car with trailer shows a slight saving on a car-mile basis, but over 10 per cent. more energy consumption per ton mile than a train of two similar motor cars.

The six-motor train seems to be worthy of special consideration for this class of service. Its running time was very nearly as good as that of the eight-motor train or of the single four-motor car, and at the same time it showed a saving of 7.4 per cent. in energy consumption per ton mile and about twice as much per car mile. It has none of the disadvantages of trailer operation and it would seem to be entirely feasible to operate the two-motor cars singly during the middle of the day for a larger part of the year and thus secure the still greater energy economy as shown by the two-motor car tests. If, however, weather or rail conditions make it advisable, the four-motor cars could be run throughout the day, while the combination of a two-motor and a four-motor car in the rush hours would meet the conditions of heavy travel much more satisfactorily than a train of two two-motor cars, and practically as well as an eight-motor train. The report on the Public Service tests concludes that train operation in city service is desirable under certain conditions and during certain periods of the day. This is indicated (1) by the facilities which train operation provides for handling rush-hour loads and traffic of extraordinary proportions; (2) by the relief offered through congested sections by operation in trains instead of as single units; (3) by the reduction in platform expense which train operation makes possible in comparison with single cars.

In the operation of two-car trains, it is desirable that all entrances should be at the middle of the train (near side trailer and far-side motor) in order to eliminate the hesitation factor which existed in the Public Service tests.

Miscellaneous Equipment for Interurban Cars. The Committee on Maintenance and Inspection, A.E.R.E.A., 1908, recommends that interurban cars should never be put in service without the following miscellaneous equipment:

Three sets of flags (red, white and green); telephone, where standard to the road; classification and marker lamps where oil lamps are used; two trolley pickups; one coupler or pulling bar; one pull rope; coupling link and pin; extra supply of air pumps and light fuses (also car and control fuses where used); fire extinguisher in working order; one extra trolley pole, fully equipped, on top of the car; one extra trolley rope, or, better still, one extra retriever equipped with rope; one trolley retriever in its place on the rear dash; one headlight in its place on the front dash, for signal use. Fuses and torpedoes should be on each car. The crew should have both red and white lanterns in good condition, and sufficient tools to change the trolley pole or make other light repairs. Interurban cars should also carry a wrecking outfit with axe, saw, jack and crowbar.

Cleaning Cars. The following rules governing car cleaning at the Boston Elevated Railway Company's surface car house, as given in the report of the A.E.R.E.A. Joint Committee on Engineering Accounting, 1912, were carefully worked out by the Department of Rolling Stock and Shops after an extended study of the work. It covers every detail of cleaning on various types of cars, names, methods of work, tools to use, number of men to do work, intervals at which work should be done, time required for the job, etc. These rules are followed except in particularly cold weather or under other unusual weather conditions, when the rules may be suspended by the direction of the car house foreman. It should be noted that the "Time Required," in the first tabulation, is a maximum on 25-ft. box cars, the time allowed on other cars being proportional to the surface covered.

26½-FT., 25-FT., AND 20-FT. BOX CARS DAILY CLEANING—EXTERIOR OF CAR

No.		Time required
1	Mop painted work and side glass (except during stormy weather).	One man 10 minutes
2	Clean vestibule glass with damp chamois and towel.	One man 10 minutes
3	Mud splashes to be removed with wash brush and clean water.	One man 10 minutes
	DAILY CLEANING—INTERIOR OF CAR	
4	*Sanding:* Sand boxes to be tested by dropping sand on the rail, then fill sand boxes.	One man 4 minutes
5	*Sweeping car body, vestibule and steps* by the following method: Sprinkle lightly steps, platform and interior floor with disinfectant in solution with water. Turn up cushions. Sweep floor thoroughly toward and onto vestibule. Dirt from vestibule and steps to be swept into receptacles. Special attention to be given to dirt around controllers and brake ratchets and behind cab doors. Proper scraper to be used for removing heavy dirt.	One man 12 minutes
6	*Dusting:* Note: At least 2 hours' time to elapse between sweeping car and dusting same. Cars to be dusted as follows: All of the interior of car body and vestibules and fixtures of same, including window and monitor glass to be dusted with feather duster, except the following, viz.: lamps, hand strap poles, hand straps, window sills, dasher sills, register glass which are to be wiped with dry towel. Care should be taken to see that lamps are not left loose in socket.	One man 6 minutes

Defects in Cars. Car cleaners are required to report to foreman on duty immediately (giving car number in all cases), the following defects, viz.: Sand boxes failing to work properly, defective light circuits, missing spare lamps, broken glass, missing sign sticks, missing cardboard signs, defective curtains, broken register or bell cords, exceptional disorder conditions in cars requiring special attention, or any other defects that may come to their attention.

PERIODICAL CLEANING—EXTERIOR OF CAR

No.		Frequency of period	Time required
7	*Washing:* Wash cars all over below roof using clean water in troughs or pails and wash brushes. In connection with this job the front windows (inside) of vestibule to be washed with brush and water. Vestibule dasher sills to be wiped dry.	After each storm.	Two men 15 minutes each.
8	*Painted wood work, dashers and exterior* signs to be washed with water and oil soap. Saponified water to be applied to colored work with wash brushes, to white work with suitable scrub brush. All soap to be removed from car body afterward by thorough rinsing with clean water. Windows to be thoroughly cleaned after this process.	Two months.	Two men 2 hours each.
9	*Monitor and ventilator glass* to be cleaned by wiping with dry towel.	Two weeks.	One man 12 minutes.
10	*Headlights* to be cleaned with oil soap, water and waste.	Once a month.	One man 10 minutes.
11	*Headlights* to be painted after thorough cleaning.	Twice a year.	One man 10 minutes

PERIODICAL CLEANING—INTERIOR OF CAR

12	*Glass* side window glass, bulkhead glass and vestibule glass to be cleaned with damp chamois.	Once a week.	One man 30 minutes.
13	*Curtains* to be thoroughly cleaned with whisk brooms and then wiped with towels.	Two weeks.	One man 15 minutes.
14	*Platforms and steps* loosening all caked dirt with suitable scraper and removing same with whisk broom.	Two weeks.	One man 10 minutes.
15	*Dashers* to be washed and scrubbed using corn broom and oil soap and water.	Once a month.	One man 10 minutes.
16	*Dashers* to be painted with quick drying paint furnished by Bartlett St. Shops, care to be taken that paint is thoroughly dry before car goes out. (Paint will probably require 8 hours to dry.)	Twice a year.	One man 10 minutes.
17	*Wood work in car bodies and vestibules* including monitor glass to be cleaned by first wiping with dry towel and then washed with damp sponge. Specially clean water to be used on this job. Heel boards only may be washed with oil soap and water if conditions require it.	Once a month.	One man 1 hour.

SEMI-CONVERTIBLE CARS NOS. 1, 2, 3, 4 AND 4-A

DAILY CLEANING—EXTERIOR OF CAR

No.		Maximum time required
20	Mop painted work and side glass (except during wet weather).	One man 15 minutes.
21	Clean vestibule glass with damp chamois.	One man 15 minutes.
22	Mud splashes to be removed with wash brush and clean water.	One man 10 minutes.
	DAILY CLEANING—INTERIOR OF CAR	
23	*Sanding:* Sand boxes to be tested by dropping sand on rail, then fill sand boxes. Cars to be sanded before being swept.	One man 4 minutes.
24	*Sweeping car body, vestibule and steps* by the following method: Sprinkle lightly, steps; platforms and interior floor with disinfectant in solution with water. Using a suitable broom, sweep side sills and floor under transverse seats, sweeping all dirt onto center matting, sweep center matting and floor space not previously covered toward and onto vestibule floor. Dirt from vestibules and steps to be swept into receptacles. Special attention to be given to removing dirt around air-brake pipes, hand brake ratchets and behind cab doors. Proper scraper to be used for removing heavy dirt.	One man 20 minutes.
25	*Dusting:* Note: At least 2 hours, time to elapse between sweeping car and dusting same. Cars to be dusted as follows: All of the interior of the car body, vestibule and fixtures of same, including window and monitor glass to be dusted with feather duster except the following: lamps, hand strap rails, window sills, dasher sill, seat arms and register glass, which are to be wiped down with dry towel. Care should be taken to see that lamps are not left loose in socket.	One man 10 minutes.

Defects in Cars. Car cleaners are required to report to foreman on duty immediately (giving car number in all cases), the following defects, viz.: Sand boxes failing to work properly, defective light circuits, missing spare lamps, broken glass, defective curtains, defective doors, broken register or bell cords, exceptional disorder conditions requiring special attention or any other defects that may come to their attention.

PERIODICAL CLEANING—EXTERIOR OF CAR—SEMI-CONVERTIBLE

No.		Frequency of period	Maximum time required
26	*Washing:* Wash cars all over below roof using clean water in troughs or pails and wash brushes. In connection with this job the front windows (inside) of vestibule to be washed with brush and water. Vestibule sill to be wiped dry.	After each rain storm.	Two men 20 minutes each.
27	*Painted wood work, dashers and exterior signs* to be washed with water and oil soap. Saponified water to be applied to colored work with wash brushes, to white work with scrub brush. All soap to be removed from car body afterward by thorough rinsing with clean water. Windows to be thoroughly cleaned after this process, using pumice stone if necessary to remove the rust accumulation.	Every 2 months.	Two men 2½ hours each.
28	*Monitor glass* to be cleaned by first wiping with dry towel then cleaning with damp chamois. Includes interior and monitor glass No. 1, 2, 3 cars.	Every 2 weeks.	One man 15 minutes.
29	*Headlights* to be cleaned with oil soap, water and waste.	Once a month.	One man 10 minutes.

PERIODICAL CLEANING—INTERIOR OF CAR—SEMI-CONVERTIBLE

30	*Glass:* Side glass, air door glass and vestibule glass to be cleaned with damp chamois.	Once a week.	One man 40 minutes.
31	*Curtains:* To be thoroughly cleaned with whisk broom and then wiped with dry towel.	Two weeks.	One man 20 minutes.
32	*Platform and steps:* Removing all caked dirt by first loosening dirt with suitable scraper and removing same with whisk broom.	Two weeks.	One man 10 minutes.
33	*Dasher washing:* To be washed and scrubbed using corn broom, oil soap and water.	Once a month.	One man 30 minutes.
34	*Dasher painting:* To be painted with quick drying paint furnished by Bartlett St. shops. Care to be taken that paint is thoroughly dry before car goes out. (Paint will probably require 8 hours to dry.)	Twice a year.	One man 10 minutes.
35	*Wood work and side sills in car body and vestibules* also monitor glass to be cleaned by first wiping with dry towel and then washed with damp sponge, specially clean water to be used on this job.	Once a month.	One man 2 hours.

Track Sanders. (W. H. Evans, Ill. Elec. Ry. Assoc., 1912.) There is no question that satisfactory results from the use of sand will depend very largely upon the efficiency of the sanding device itself and the character of material with which it is supplied. Owing to the restricted conditions on an electric car, it is usually very difficult to install the older types of mechanical gravity sanders with anything like a satisfactory arrangement. This difficulty is also augmented on account of the very sharp curves and other conditions which usually prevail or at least restrict the operation to some few particularly bad locations. This has led to the general use of pneumatic sanders as being superior to the gravity type in that they are more readily applied and have the advantage of distributing the sand evenly and expeditiously at the proper point on the rail directly ahead of where the front pair of wheels makes contact with the rails. The sand should be applied only in sufficient quantity to give maximum traction and braking power, and it is especially important that the application should be just previous to or at the time of the application of the brakes and before the braking power is high enough to skid the wheels. This applies particularly to emergency brake applications and is one of the special advantages of the pneumatic type over any of the gravity sanders. The pneumatic type, however, requires very careful installation and arrangement of the piping connections in order to insure reliable and positive results when called upon under the most trying conditions of weather and roadway. It is also very necessary to use a device requiring the minimum amount of air and sand as well because of the tendency to overload the compressor with minor pneumatic devices which were not taken into consideration when the capacity of the air compressor was determined. The flexible connection between the sand box, usually carried inside the car, and the discharge pipes attached to the trucks is usually a source of considerable trouble and requires careful attention. The style of the sand valve should be such as to avoid useless waste of air. It should also be located conveniently near the brake valve so that the two operations of applying sand and setting the brakes can be done in emergency at practically the same time.

Character of Sand. The best quality of good sharp quartz sand, thoroughly dried and screened and free from dirt or soil, should be used. Dirty sand is more susceptible to moisture and consequently its tendency to clog up the pipes is greater, aside from the harm it may do after reaching the rail. Lake sand has been found quite satisfactory and is extensively used in pneumatic sanders on account of its fine, even grain and freedom from foreign matter. It is also easily dried and screened and is generally economical. The character of the sand is worthy of more important consideration than is apparently usually given to it. In some cases it is entirely lacking in the essential qualities and has a tendency not only to defeat the object for which it is applied, but actually to assist in creating a more serious condition.

Car Heating. The following notes on car heating are principally from the Report of the Committee on Equipment, A.E.R.E.A., 911. The usual means of heating cars are (1) coal stoves, direct method; (2) coal stoves, indirect method, similar to hot air furnace used for heating of houses; (3) hot air heaters, air blast, motor driven; (4) hot water heaters; (5) electric heaters. The characteristics of the various methods should be considered with regard to the following points: (1) ability to heat car to uniform temperature; (2) first cost, completely installed on car; (3) maintenance; this will include repairs, renewals, replacements, etc.; (4) cost to operate; in the case of hot water heaters, this will include fuel and labor only; in the case of electric systems, power only, and in the case of the hot air blast heater using coal, fuel, labor and power; (5) weight of system complete as installed on the car ready to operate; (6) fire risk; (7) reliability; (8) regulation; this refers to ability to regulate the heat to outside temperature; (9) space occupied; (10) appearance; (11) attention required from car crew; (12) cleanliness, which will include freedom from dust, ashes and obnoxious gases; (13) adaptability and relation to ventilation systems.

Aside from the ordinary coal stove, the three principal heating systems are the hot air heater, hot water heater and electric heater.

The Hot Air Heater. In this system the air is heated by a coal fire and forced through suitable ducts along the side of the car by motor-driven fans. By its use it is possible to secure quite uniform heating of the car. The heat being applied along the floor line results in dry floors, which is a very strong point in its favor. The first cost is rather high, but as the equipment becomes better developed this cost should be somewhat lower. The maintenance of this system is considerable, but exact data are not yet available. The cost to operate, including only the items of coal, labor of attendance and cost of electricity for the motor is comparatively low. The weight depends upon type and size of car, but is practically the same as electric, and less than hot water heaters. The fire risk is practically the same as in the case of hot water heaters. The reliability of the heater in its present state of development seems to be an open question. The regulation is not so good as it should be, but will undoubtedly improve as the apparatus is further developed. When this system is used in conjunction with exhaust ventilation, the regulation is better. The space occupied is perhaps greater than with hot water heaters. The appearance compares favorably with other types of coal heaters. Considerable attention is required from the car crew from time to time in order to keep fire in proper condition, but where the heater can be placed near the conductor or motorman, this is readily accomplished. It is not so clean as the electric system, but compares favorably with hot water. As this system is designed to provide for ventilation, it is readily adapted to that end.

The Hot Water Heater. This system possesses many valuable characteristics, among which are independence of the electric power supply, which is quite a consideration in interurban work where long runs are made and the power supply is subject to interruption. By the use of this type of heater it is possible to heat the car very uniformly. The efficiency of hot water heaters will fall off materially if the pipes and coil are not kept reasonably free from scale and other deposits. The first cost is not so high as that of the hot air system. The maintenance is higher than that of the electric system. The cost to operate, including only the items of fuel and labor, is approximately the same as for the hot air heater. The weight of the hot water apparatus is high and has long been one of its chief drawbacks, but the latest types show improvements in this respect. The fire risk is substantially the same as for the hot air heater. In case of accident there is a hazard from the fire in the coal stove. The reliability is very good. The regulation is comparatively poor. It takes some time for water to take up heat and, conversely, it takes some time for water to lose its heat. The space occupied is considerable and, except on single-end cars, this space is valuable as seating or standing room. The hot water heater with its expansion drum, water glass gage, etc., does not add to the appearance of a car, except where it is practicable to partly enclose the apparatus. Attention is required from time to time, but the work is small and where the heater can be located close to one of the crew, it does not take him from other duties. The hot water heater as usually installed produces dust, and very frequently obnoxious gases. The heating elements being pipes located one above the other near the floor line, it is easy to adapt this system of heating to any practical scheme of ventilation.

The Electric Heater. It is perfectly possible to secure uniform temperature throughout the car. The first cost is lower than that of any of the other modern systems. When the electric heater is carefully installed with wiring in conduit, the maintenance is very low, being considerably less than that of any of the other modern systems. The cost to operate, which includes energy only, is variable, depending on the size of car, the range of temperature, the cost of energy, and whether the peak load on power stations comes in the heating seasons or not. In general, the cost of operation, as defined above, is high. There are many cases, however, where this method of heating will show the greatest net economy. The weight is the least of any of the modern heating systems, except in some cases, where it is practically the same as the hot air heater. Where the wiring is properly installed in conduit the fire risk is practically nil. This system is very reliable. The regulation is best of all, it being possible to follow closely and without trouble rapid changes in outside temperature. The space occupied is very small and is not useful for standing or seating capacity. The appearance of such parts as are exposed is very good. The electric heating system requires the minimum amount of attention from car crew. This type of heater is clean and free from dirt or obnoxious gases. The heating units being subdivided and located under the car seats or along the truss plank are readily adaptable to any practical system of ventilation.

Comparative Costs of Car Heating. As a comparison in costs of heating a car by the three modern systems, the following estimate is given. The figures are based, in general, on results obtained in practice and are considered fair and reliable.

Assumptions: 32-ft. car body; heating season, 145 days; lowest temperature, about zero; municipal requirements, 50 deg. F.; cost of energy, 1.4 cents per kilowatt hour at the trolley; cost of coal, $7.75 per ton.

TOTAL COST FOR 1 YEAR CHARGEABLE TO CAR HEATING

	Electric heater	Hot water heater	Hot air heater
Cost of power	$137.03	....	$8.22
Repairs and maintenance	1.09	$4.35	2.90
Interest and depreciation	8.80	18.75	18.60
Coal	....	47.76	47.76
Labor of attendance	....	8.70	8.70
Hauling weight (4 cents per pound per year)	20.00	60.00	20.00
Insurance charge	....	12.00	12.00
Total cost per car	$166.92	$151.56	$118.18

The above figures are based on the following data and assumptions:

	Electric heater	Hot water heater	Hot air heater
First cost, installed	$80.00	$125.00	$155.00
Interest and depreciation, per cent	5 and 6	5 and 10	5 and 7
Weight installed, pounds	500	1,500	500
Coal consumption per day, pounds	....	85	85
Power consumption, kilowatts	5.0 average for heating season	....	0.3
Repairs and maintenance, cents per day of heating season	3/4	3	2
Cost of car	$6000.00	$6000.00	$6000.00
Investment in car houses per car	$1500.00	$1500.00	$1500.00
Hours per day per car	13½	13½	13½
Labor of attendance, cents per day of heating season	....	6	6
Heating season, days	145	145	145
Extra insurance over electric heaters:			
Cents per $100 on car houses	....	10	10
Cents per $100 on cars	....	17½	17½

Peak load on power stations during heating season.

From the above it is seen that, *under the conditions assumed*, the relative total economy of the three principal heating systems is as follows: Hot air system, first; hot water, second; and electric, third. If the conditions are different from those taken as typical, different results will be obtained; for example, if, under the above assumptions, the peak load on power stations came in summer time, then the electric heating system would show the greatest total economy. This results from the fact that in the latter case the proper charge for energy would be only the cost of coal per kilowatt-hour, or say 0.5 cent instead of 1.4 cents. It is, therefore, readily apparent why it is impossible to say off-hand that the cost of car heating is so much per day unless all the conditions are known. As stated before, in the choice of a system for heating cars some consideration other than that of total economy may govern, such as appearance, space factor, ability to regulate, and fire hazard.

In figuring the power consumption of electric heaters, the following method will probably give the most accurate results: Obtain from the weather bureau temperature readings for each winter for several years. Plot a curve showing variation of temperature for each day of the heating season. Find what circuit in heaters is used for various temperatures and plot a power curve which will indicate the average kilowatts per day.

In the use of hot water or hot air heaters there is a tendency on the part of the car crew to use less coal than is necessary to keep the cars at a uniform temperature during the time they are in service, while with electric heaters the tendency is to put on three points where two points would suffice. This may give rise to false ideas of the relative costs of the various heating systems.

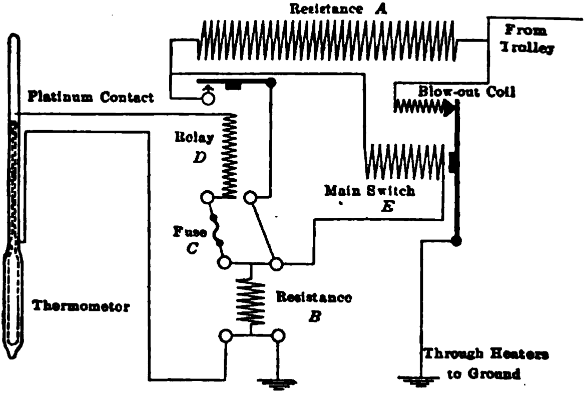


FIG. 42.—Electric thermostat control for car heaters.

In the installation of electric heaters, it is preferable to have a comparatively large number of heaters rather than a few, even though the power consumption is on the same basis, on account of the better distribution of the heat. For localities where the temperature reaches zero or lower, it is well to have about 4.5 watts per cubic foot of car body, otherwise it may be difficult to maintain the cars comfortable when low temperatures prevail.

Thermostatic Control of Electric Heaters. A number of devices have been designed for the automatic regulation of electric heaters, the successful operation of which very greatly reduce the cost of electric heating, in some cases the tests showing a saving of some 50 per cent. One type of thermostatic control is illustrated in Fig. 42, by reference to which the operation of the control circuit is explained as follows: Normally current flows through resistance *A*, the magnet coil of switch *E* and resistance *B* to ground, and switch *E* is held closed. Current then flows direct from the trolley through the out coil and the contacts of switch *E* and then through the rs to the ground. As the car warms up, the column of mercury in the thermometer rises. When it touches the upper platinum contact, a current of very low voltage is shunted around resistance *B*, through fuse *C*, the coil of relay *D* and the thermometer, to ground. Relay *D* is thus energized and its contacts close. This short-circuits the magnet coil of switch *E*, and that switch opens by gravity, cutting current off the heaters. When the temperature falls so that the mercury of the thermometer leaves the platinum contact, the thermometer circuit is broken, and relay *D* is no longer energized. Therefore, its contacts open, breaking the shunt around the coil of switch *E*. The latter is then energized and closes, turning current on the heaters. A rise and fall of less than 1 deg. is sufficient to turn the heaters off or on as required.

Ventilation of Cars. Authorities differ as to the amount of air to be supplied per person per hour, in order to provide a reasonable standard of air purity. An ordinance of the city of Chicago on this subject calls for the supplying of 350 cu. ft. per hour per passenger (based on maximum standing and seated load); provided, however, that the air in the car shall at no time show more than ten parts of CO_2 in 10,000 parts. It was found possible to meet this requirement by any one of several ventilating systems.

Monitor Deck Windows. The usual method of obtaining ventilation in electric railway cars has been to provide a monitor deck or clear story in which there are a number of small windows that can be opened. The ventilation afforded by these small windows is largely by dilution; that is, such air as may enter serves to freshen the air in the car. The chief objection to the system is that, under some conditions of operation, strong draughts are created which are objectionable to passengers.

Types of Ventilators. Ventilation systems other than monitor windows have been worked out principally along two lines: those operated by the movement of the car through the air and those operated by motors. The first are usually called the automatic systems and the second, mechanical systems. Automatic ventilators are usually "Exhauster" and should be so designed as to exclude rain and snow and to prevent gusts of air coming into the car. The action of automatic systems is, of course, variable, depending on the velocity of the car and the direction and force of the wind. The mechanical systems, of which there are two principal kinds, the "Exhauster" type and the "Blower" type, are positive and practically independent of motion of the car or velocity of the wind.

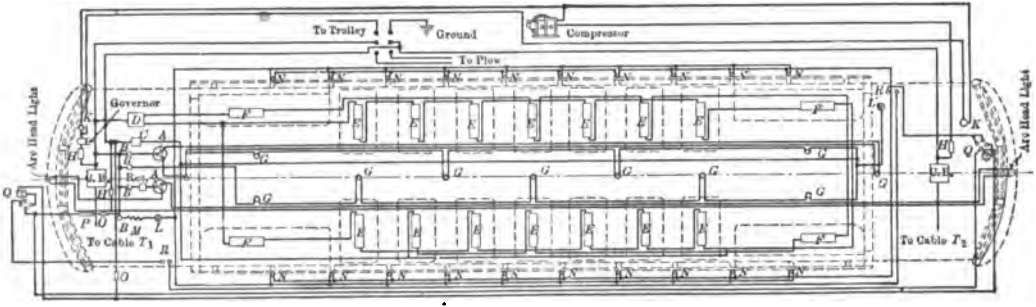
Mechanical System of Ventilation. A typical mechanical system consists of a motor-driven exhaust fan located on the vestibule roof, or other practical point, an exhaust chamber formed in the upper ceiling of the car, openings located at various points in the ceiling and intakes located at several points in the floor and connected to the electric heaters. The cold air thus is made to pass over the heating surface before coming into the car body which is generally appreciated as a very desirable feature. Tests show that consumption of energy for heat is not increased by this method. The fan-motor set consists of a ½-h.p. motor, direct-connected to a specially designed 9-in. cone fan. This fan will handle about 33,000 ft. of air per hour under normal conditions of line voltage.

The motor is connected direct to the 500-volt trolley circuit through a standard combination snap switch and fuse, and is started and stopped by means of this switch. The motor and fan are mounted in a suitable metal housing which is connected to the exhaust chamber. The fan discharges through protected openings in each side of the housing. The exhaust chamber in the upper part of the car is formed by dropping down the ceiling about 4 in. from the roof framing and is continuous from end to end of the car body. Communication between the car interior and the exhaust chamber is provided by a number of openings, each containing a circular adjustable register. By proper adjustment of the registers a uniform velocity of air through all of them is obtained. There are several intakes, half being located on each side of the car under the seats in such a manner as to be readily connected to the electric heaters. The connection between the screened opening through the car floor and the electric heater is made with a pressed metal duct. The size and number of the intakes is such as to permit of a maximum velocity of the air of about 400 ft. per minute, which is hardly perceptible to passengers.

Automatic System of Ventilation. The automatic systems installed are of several different kinds, but all depend upon aspirator action for their operation. One of these automatic systems which has shown fair results comprises a number of exhausters located along each side of the monitor roof and attached to panels placed in the monitor or deck window openings. An opening in the panel communicates with the exhauster. These exhausters are also designed for use with plain arch roof cars. Intakes similar to those described in connection with the mechanical system are located in the floor and provide a supply of fresh air. The exhausters are rectangular sheet-metal boxes projecting outwardly from the panels to which they are secured, having openings top and bottom, and provided on the middle of each side face with V-shaped projections. The V projections are placed horizontally on the faces of the exhausters and split the air into two streams, one following upward and the other downward. The air streams flow past the openings of the exhauster and by induction draw the air out from the car.

Location of Air Intake. There is a tendency to abandon intakes near the floor line owing to street dust. On a number of European lines, notably the Budapest suburban system, louver type ventilators are installed over the side sash instead of using a monitor roof.

Tests on Ventilating Systems. On Feb. 4 and 5, 1908, a test was made on five cars of the Springfield (Mass.) Railway, three cars being equipped with the ordinary deck sash and two with a self-acting intake and exhaust system. The outside temperatures during the test ranged from 10 deg. to 24 deg. F. and averaged about 17 deg. F. Anemometer readings on the ventilated cars showed intakes of from 300 lin. ft. to 900 lin. ft. of air per minute, with exhausts a little lower. Calibrated thermometers were hung at various levels in the cars and runs were made in both ventilated and unventilated cars during approximately the same hours of the day and under similar ~~~rvice conditions. In the ventilated cars, sixty-one thermometer

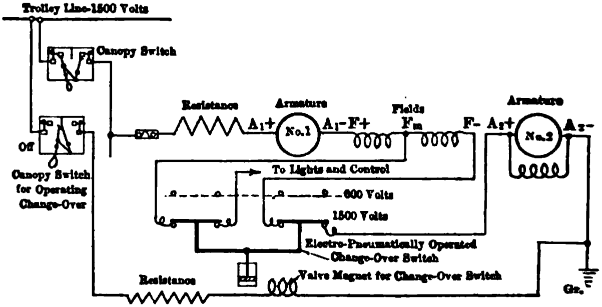


A 3 Point Snap Switch
B Combination Switch & Cut-out
C 15 Amp. Cut-out (Inclosed Fuse)
D Switch & Cut-out
E Heater, 375 Watts
F Heater, 375 Watts
G Socket, Shade Holder & Holophane Reflector
H 10 Amp. (Inclosed Fuse)
K 500 Volt 10 Amp. Snap Switch
L Buzzer
M Resistance Unit
N Push Button
O 1 Amp. Inclosed Fuse
P 5200 Ohm Resistance
Q Light Box & 2 Way Switch
R Door Switch

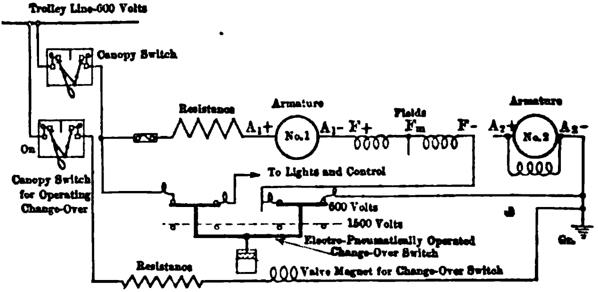
FIG. 43.—Wiring of minor car circuits, Capitol Traction Company.

readings were taken, and on the unventilated cars, fifty-three readings were taken with all deck sash closed, and seventeen with four deck sash open. The following is a comparative statement of all thermometer readings which were taken in both types of cars:

	Ventilated cars	Unventilated cars
Average temperature, all readings...	55 deg.	49½ deg.
Average temperature, at rack......	56 deg.	50 deg.
Average temperature, at seat......	55½ deg.	49¼ deg.
Average temperature, at floor......	51 deg.	43 deg.
Average temperature, at vestibule..	16 deg.	17½ deg.



1500 Volt Connections



600 Volt Connections

FIG. 44.—Minor circuits on high voltage D.C. system.

Several years ago the city of Chicago, through its health department, demanded that the street railways of that city should provide proper ventilation in their cars, to which the railways agreed, with the proviso that the type of ventilating apparatus to be used must first be determined by the health board. Dr. Evans, chief of the health department, invited the various car ventilator manufacturers to furnish equipments of their devices for test purposes, stipulating, however, that the air intake must be at the floor line, over duct-covered electric heaters, and exhaust at the monitor. He further specified that the intake devices must provide a minimum of 28,000 cu. ft. of air per hour when cars were standing still or moving slowly in the Loop district. Under these specifications, a record was made by a self-acting system of from 25,000 cu. ft. to 58,000 cu. ft. of floor intake and 26,000 cu. ft. to 62,000 cu. ft. monitor exhaust.

Heating and Lighting Circuits. The location of heaters, lights and other minor electrical devices will vary with the general design of individual cars and to meet local requirements, and it is not possible, therefore, to make any general statement which will apply to all cases. However, Fig. 43, which shows the wiring of minor circuits as installed by the Capital Traction Company, is given as a good illustration of a wiring diagram for such circuits.

Operation of Minor Circuits with High Voltage Direct-current Systems. With high voltage direct-current systems it is necessary to secure reduced voltage for the control circuits, lights, air compressors, etc. A common method of accomplishing this end is by the use of a dynamotor, the connections for which are shown in Fig. 44 (see also Fig. 29, p. 515). It is essentially a compound-wound motor, having two independent armature windings, each connected to its own commutator, a shunt field being added for light loads. The operation is the same as two motors in series and on 1500 volts sufficient current is drawn from the connection between the two motors to feed lights and control circuits at 750 volts. One end of the shaft extends to a clutch through which connection is made to the air compressor, and the compressor is operated intermittently through the opening and closing of the clutch under the action of the governor. Where 600-volt operation is also required, a change-over switch is utilized to transform the dynamotor into a motor with only one armature winding in circuit, as shown in Fig. 44.

Car Lighting. Electric car lighting, formerly exclusively by means of the carbon filament lamp, has recently been made much more economical by the use of the tungsten lamp, which gives an efficiency of 1.25 watts per candle-power and has a useful life equal to or greater than that of the carbon lamp. On account of its resistance characteristics, the tungsten filament is much less susceptible to changes in candle-power with varying voltage than the carbon, so that it will stand a higher overvoltage than the latter, and will also give a fair illumination at low voltage under which the carbon lamp gives practically no light. Tests made by the Bay State Street Railway (Elec. Ry. Jour., 1912–1913) indicate the economy of using a small number of large tungsten units rather than a large number of small units, as was the almost universal practice with carbon lamps. The first table on page 574 shows the comparative values of the intensity of illumination in various parts of the car with various combinations of tungsten and carbon lamps (1912 tests).

Later tests, comparing one car equipped with ten 56-watt tungsten lamps with holophane reflectors, and the other with twenty-

	28-ft. cars		34-ft. cars	
	Car No. 1407, 6 60-watt Mazdas, ft.-candles	Car No. 1400, 16 64-watt carbons, ft.-candles	Car No. 1321, 6 60-watt Mazdas, ft.-candles	Car No. 1324, 21 64-watt carbons, ft.-candles
Platform:				
Maximum	3.5	1.0	2.5	2.3
Minimum	2.3	0.5	1.1	1.6
Average	2.9	0.8	2.1	2.0
Center line car body:				
Maximum	5.7	2.9	4.4	3.5
Minimum	2.8	1.4	2.0	2.1
Average	4.0	2.2	2.9	2.9
End seats:				
Maximum	3.6	2.4	3.4	3.0
Minimum	1.0	1.9	2.1	2.1
Average	2.3	2.2	2.8	2.5
Inboard edge cross seats:				
Maximum	4.8	3.9	3.4	2.9
Minimum	3.5	2.1	1.8	1.9
Average	4.4	2.7	2.3	2.4
Outboard edge cross seats:				
Maximum	5.5	3.1	2.8	2.7
Minimum	3.3	1.9	1.5	1.7
Average	4.4	2.6	2.0	2.2
Average for whole car	3.6	2.1	2.4	2.4

five 64-watt carbon lamps, also show the intensity of illumination 3 ft. from the floor, as follows:

	Carbon car	Mazda car
Average foot-candle intensity along center line of aisle	1.70	3.91
Average foot-candle intensity half way to window sills	1.46	3.15
Average foot-candle intensity along window sills	1.26	2.14
Average foot-candle intensity across forward platform (platform lamps extinguished).	1.28	1.32
Average foot-candle intensity across rear platform (platform lamps lighted).	1.62	3.03
Total wattage on car	1600.00	560.00
Wattage in car body	1280.00	336.00
Effective lumens per watt in car body	0.41	2.37
Efficiency of light utilization, per cent	15.8	31.2

WATTAGE REQUIRED TO PRODUCE AN AVERAGE INTENSITY OF 3.75 FOOT-CANDLES AT APPROXIMATELY 36 IN. FROM CAR FLOOR, UNDER NORMAL VOLTAGE CONDITIONS. (A.E.R.E.A. COMMITTEE ON EQUIPMENT, 1914)

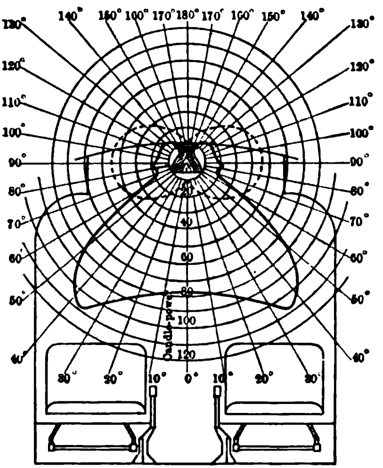
Equipment	Length of car body					
	25 ft.	30 ft.	35 ft.	40 ft.	45 ft.	50 ft.
Bare carbon lamps	1,700	2,050	2,390	2,730	3,070	3,410
Bare Mazda lamps	525	630	735	840	945	1,050
Light density opal reflectors with Mazda lamps.	340	405	475	540	610	675
Medium density opal reflectors with Mazda lamps.	290	345	405	460	520	580
Heavy density opal reflectors with Mazda lamps.	240	285	330	385	430	475
Prismatic clear reflectors with Mazda lamps.	235	280	325	375	420	470

SIZE AND NUMBER OF LAMPS, AND TYPES OF REFLECTORS REQUIRED TO PRODUCE A MINIMUM INTENSITY OF 3.75 FOOT-CANDLES AT APPROXIMATELY 36 IN. FROM CAR FLOOR, AT RATED VOLTAGE, FOR VARIOUS LENGTHS OF CAR BODIES. (A.E.R.E.A. COMMITTEE ON EQUIPMENT, 1914)

Lamps		Length of car body					
No. of units in body of car	Kind	25 ft.	30 ft.	35 ft.	40 ft.	45 ft.	50 ft.
5	64-watt carbon.	....	....	....	....	....	....
	23-watt Mazda.	Not	sufficie	nt watt	age	Too wid	e space
	36-watt Mazda.	....	....	....	....	....	....
	56-watt Mazda.	Prism H. opal	Prism H. opal	....	....	....	....
	94-watt Mazda.	M.opal L. opal	M.opal L. opal	Prism H. opal M.opal	Prism H. opal M.opal	....	....
10	64-watt carbon.	....	... Not	sufficie	nt watt	age....	....
	23-watt Mazda.	Prism	Prism	Prism	....	....	....
	36-watt Mazda.	H. opal M.opal L. opal	H. opal M.opal L. opal	H. opal			
	56-watt Mazda.	....		M.opal L. opal	Prism H. opal M.opal L. opal	Prism H. opal M.opal	Prism H. opal
	94-watt Mazda.	Bare	Bare	Bare	Bare	L. opal	M.opal L. opal
15	64-watt carbon.	....	....	....	....	....	....
	23-watt Mazda.	Prism H. opal M.opal L. opal	Prism H. opal M.opal	Prism H. opal	Not su	fficient	wattage
	36-watt Mazda.	....	L. opal	M.opal L. opal	Prism H. opal M.opal L. opal	Prism H. opal M.opal	Prism H. opal
	56-watt Mazda.	Bare	Bare	Bare	Bare	L. opal	M.opal L. opal
	94-watt Mazda.	....	....	....	....	Bare	Bare
20	64-watt carbon.	....	... Not	sufficie	nt watt	age....	....
	23-watt Mazda.	Prism H. opal M.opal L. opal	Prism H. opal M.opal L. opal	Prism H. opal M.opal	Prism H. opal M.opal	Prism H. opal	....
	36-watt Mazda.	Bare	Bare	L. opal	L. opal	M.opal L. opal	Prism H. opal M.opal L. opal
	56-watt Mazda.	....	Bare	Bare	Bare	Bare	Bare
25	64-watt carbon.	....	... Not	sufficie	nt watt	age....	....
	23-watt Mazda.	Prism H. opal M.opal L.opal Bare lamp	Prism H. opal M.opal L. opal	Prism H. opal M.opal L. opal	Prsim H. opal M.opal L.opal	Prism H. opal M.opal	Prism H. opal
	36-watt Mazda.	....	Bare	Bare	Bare	L. opal	M.opal L. opal
	56-watt Mazda.	....	....	....	....	Bare	Bare

Fig. 45 shows the comparative light distribution from bare lamps and lamps with reflectors.

The Committee on Equipment, A.E.R.E.A., 1914, stated that the minimum acceptable intensity of car illumination is 1.5 foot-candles, and in order to provide for a voltage drop to approximately 80 per cent. normal, the car lighting system should be so designed as to give an average intensity of illumination of at least 3.75 foot-candles at normal voltage in a plane 36 in. above the floor.



Dotted line curve represents distribution from bare 56-watt Mazda lamps.
Solid-line curve represents distribution from 56-watt Mazda lamp, equipped with a prismatic clear reflector.

FIG. 45.—Light distribution—Tungsten lamp with and without reflector.

Storage Battery Lighting. Especially on interurban lines with long headways, economy sometimes dictates the use of less feeder copper than will maintain a voltage which is at all times satisfactory for car lighting. In order to obviate the annoying effect of a change in intensity of illumination caused by such fluctuations, the Lehigh Valley Transit Company has equipped a number of interurban cars with ten cells of A-6 Edison storage batteries arranged in two trays of five each, each tray weighing slightly under 100 lb. This battery gives on discharge 240 ampere hours. The cars are equipped with twenty 20-watt, 16-c.p., 12-volt tungsten lamps with holophane reflectors. The lamps are wired in multiple and connected to the battery through an ampere-hour meter which is compensated to run 20 per cent. slower on charge than on discharge and with a pointer showing the limiting capacity of the battery. The battery and ampere-hour meter are arranged to be removable for charging, which is done by a small motor generator set giving 50 amperes at 125 volts, which is set up in one corner of the car house and which charges six sets of batteries at one time. The batteries are pulled out of their compartment under the car onto a small truck when the cars turn in at the car house on the last trip at night, and the sets are all placed in series for charging and cut out one at a time as they come fully up to the charge, which is determined by the individual ampere-hour meter. The twenty 20-watt lamps on each car require approximately 33 amperes and the batteries will deliver that current for 7½ to 8 hours continuously, which meets uirements for one day's run. The initial voltage of the ten

Edison cells is about 13 volts at the beginning of discharge which gradually drops to 10 volts at the end of the discharge, and it is stated that there is not a sufficient variation in the candle-power of the lamps to be appreciated without the aid of a photometer. It is stated that the batteries give no more trouble in handling and charging than the ordinary arc headlight and that the system produces an absolute direct lighting system in the cars unaffected by the variation in or even entire failure of the power supply. Although the charging is somewhat inefficient, the total energy consumption including all losses is still considerably less than with the ordinary carbon lamp equipment. The expense of installation is given as only slightly in excess of $200 per car.

Electric Lighting of Train Marker Lamps. As it is absolutely essential that train marker lamps remain lighted even during a period of temporary failure of power supply, there has been some hesitancy on the part of electric railways in departing from the oil-burning lamp for this purpose. When electric lamps are used, some method should be provided for maintaining the light during such periods of failure of power supply, and this is generally done by some arrangement of storage battery. A scheme, as used by the Terre Haute, Indianapolis & Eastern Traction Company, is shown diagrammatically by Fig. 46. A 7-volt storage battery is used in series with four 110-volt, 16-c.p. lamps and a relay in the light circuit opens an auxiliary circuit which consists of four 7-volt, 4-c.p. lamps connected in parallel and operating in series with the storage battery when the trolley current is off. One 110-volt lamp and one 7-volt lamp are installed in each marker.

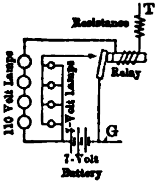


FIG. 46.—Train marker lamp wiring, Indianapolis.

Motor Bus Operation.—No tramways are allowed within the large central area of London, where a large majority of the streets are short, narrow and crooked, it being maintained that the omnibus is better adapted to operate in this congested portion of the city than is the tramway. The motor bus, which has the exclusive right on the surface within this central area, is not prohibited from operating in the territory of the tramways and is thereby able to give more complete service than the tramway. In London omnibuses are popular as a means of travel; they have a monopoly of the best traffic district; they charge a slightly higher fare than the street railways; they do not furnish all-night service; they contribute nothing toward paving maintenance or street improvements; and they require small capital account in comparison with earnings, and can operate profitably on a small margin above operating costs. Because of these facts, they are severe competitors of the tramways in London. In Paris there is no competition between the surface lines and the omnibuses, as both systems are operated by one company under exclusive rights, each supplementing the other, and the two may be considered as one system. There are three distinct types of vehicles in use: Those operated directly by gasoline engine; those operated by steam, with kerosene oil as fuel; and those opeated by gasoline engine driving a dynamo, operating an electric motor which drives the rear axle by means of a worm gear.

Cost of Motor Bus Operation. Thomas Tillings, Ltd., London, gives the following figures as to the cost per mile of running its type of cars 1,387,031 miles in 1912:

Running and maintenance	2.326 cents.
Tires	2.210 cents.
Drivers	2.514 cents.
Gasoline (including tax of 3 cents per gal.), lubricating oil, grease and paraffin	2.394 cents.
Vehicle lighting	0.150 cents.
Rents, rates, taxes, garage, lighting, water, trade vehicles, depreciation	1.972 cents.
Conductors	1.694 cents.
Body upkeep	0.470 cents.
Traffic expenses	0.534 cents.
Total cost per mile	14.264 cents.

Figures given by the Paris company are as follows:

Maintenance of chassis	4.022 cents.
Maintenance of bodies	0.928 cents.
Maintenance of tires	3.714 cents.
Brushing and cleaning, and lighting and heating of vehicles	0.821 cents.
Fuel, including the city toll thereon	6.574 cents.
Oil, grease and waste	0.650 cents.
Machinist	3.094 cents.
Expenses at the depots (supervision, lighting, motive power, tolls, shippers, etc.)	1.857 cents.
Average cost per mile	21.660 cents.

The Paris figures do not include reserve funds for renewals, nor expenses of actual operation (conductors, drivers, inspectors, etc.), nor general expenses (administration, insurance, accidents, taxes, franchise payments, maintenance of buildings, etc.).

The annual report of the Fifth Avenue Coach Co. (New York) submitted to the Public Service Commission for the First District, covering the operations of that company during the year ending June 30, 1912, states that there were in operation eighty-one vehicles during the year, which were operated a distance of 1,440,841 miles. Using this mileage and the items of operating expense given therein as a basis, the average cost of operation per mile was computed with results as follows:

Maintenance, buildings and fixtures	0.035 cents.
Tires	3.132 cents.
Maintenance, equipment	7.208 cents.
Conducting transportation	17.565 cents.
Damages and injuries	3.042 cents.
General expenses	2.308 cents.
Total operating expenses per mile	33.290 cents.
Depreciation of vehicle equipment, figures at the monthly rate of 1/36 of total cost	5.311 cents.
Taxes	2.697 cents.
Total cost per mile, including depreciation and taxes	41.298 cents.

The cost figures as given above for London and Paris are only approximate and practically of no use in estimating the cost of operation in New York and other American cities. The cost of labor, particularly skilled mechanical labor, is a great deal less in those cities than in New York, and some advantages may also be obtained in the original cost of a well-constructed vehicle as well as in the upkeep. Different types of vehicles are operated in each city, and this, no doubt, has also a large bearing on the operating cost per mile. The vehicle used in Paris is much heavier than the London type, though the capacity is about the same or less, while in New York there are various types of vehicles including some which have a much larger capacity than those of either London or Paris and of a greater weight. This probably would not, however, account wholly for the greater difference in cost of operation over that of London and Paris.

Electric Locomotives

Types of Electric Locomotives. Figs. 48 to 71, inclusive, show diagrammatically the outlines and arrangement of motors and driving apparatus for twenty-four types of electric locomotives at present in service, all except Fig. 71 being taken from Mr. F. Lydall's paper before the I.E.E., 1913.

Gearless Type Armature on Axle. The New York Central "6000" class of electric locomotive is well illustrative of this type, where the armature is mounted directly on the axle and the motor field is built into the truck frame so as to do away with all motor bearings. This type has a very low center of gravity so that it is quick to feel the irregularities of the track. (See Fig. 87, page 325, also Fig. 56, page 584.)

Gearless Type Armature on Quill Surrounding Axle. In this type the entire motor is mounted on a quill surrounding the axle and spring-suspended from the wheels. This type also has a very low center of gravity, although the entire weight of the motor is spring-supported so that the track does not get a direct blow. The New Haven locomotives are illustrative of this type. (See Fig. 88, page 326, also Fig. 57, page 584.)

Motors Geared to Axles. The later New Haven locomotives are illustrative of this type. The motors are mounted rigidly on the trucks and geared down to quills spring-supported and surrounding the axles. The connection between the quills and driving wheel is by means of long helical springs which permit the axles and journal boxes to move a total vertical distance of 3 in. in the pedestal jaws without the quills touching the axles. This type of locomotive has been built both with a single motor per axle and with twin motors of the same total capacity per axle, the latter construction making possible the same output with less weight and cost. Both motors drive the same gear, and on the New Haven single-phase system the two motors on each axle are connected permanently in series, which reduces the carrying requirements of cables and switches and makes a saving in control equipment. (See Figs. 89, 90, 91, page 326; Fig. 99, page 329, also Figs. 52, and 53, page 584.)

Motors Connected to Driving Wheels by Parallel Rods. The locomotives in use by the Pennsylvania Railroad in the New York terminal electrification are illustrative of this type, in which the motors are mounted high up in the cab and connected to drive wheels through cranks, parallel rods and jack-shafts. Neutral zone is reduced to almost nothing by the combined action of the motor rods and driving wheel rods set at an angle of about 45 deg. from each other. (See Fig. 92, page 326, also Figs. 60 to 70, pages 584, 585.)

Scotch Yoke Transmission. This type has been used exclusively for the three-phase locomotives on the Italian State Railways. It employs a Scotch yoke for transmitting power from the motors to the driving axles. The yoke drives one axle through a sliding block and the others through parallel rods connected to the yoke by knuckle pins. Spherical cranks and knuckle pins are largely used with this type of drive. (See Fig. 95, page 327, also Fig. 58, page 584.)

Combination of Gears and Side Rods or Scotch Yokes. The locomotives for the Loetschberg Tunnel in Switzerland have two motors each connected by a helical tooth gear to a jack-shaft slightly above the driving axles and thence by parallel rods to three pairs of driving wheels. The duty on the jack-shaft bearings is much easier than when side rods only are used, since the reciprocating pressures are practically all in a horizontal direction and can therefore readily be cared for. (See Fig. 55, page 584, and Fig. 71, page 586.) The locomotive for the Midi Railway in France has two motors each geared to a jack-shaft through gears located outside the plate frames of the locomotives. The jack-shafts are connected to the drive wheels through Scotch yokes similar to the Italian locomotive. (See Fig. 96, page 327.)

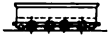
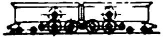
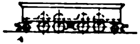
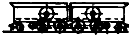
General Data on Electric Locomotives. The tables which are reproduced herewith (pages 581 and 582) from Mr. George Westinghouse's paper on "The Efficiency of Railways" give general data on ten different types of locomotives of American design for passenger service and for combined passenger and freight service, and include electric locomotives for direct current, single-phase and three-phase alternating current and others adapted for operation on either single-phase alternating current or direct current.

Tractive Effort of Various Classes of Locomotives. Fig. 47, reproduced from a paper by H. Parodi before the Societe Internationale des Electriciens in Paris, 1913, shows the draw-bar pull at various speeds of different classes of steam and electric locomotives. This curve not only brings out the tractive effort characteristic of the steam and electric locomotive but also shows the characteristic of the direct-current, single-phase and three-phase locomotive.

Mechanical Characteristics. The mechanical design of any locomotive requires that there must be strength in all parts sufficient for the maximum service; the locomotive must be adaptable to the desired speed; it must suit the curves over which it is to operate; and it must have wearing characteristics for continuous service to reduce the wear and tear to an operative amount. From performance of actual locomotives it seems reasonable to con-

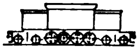
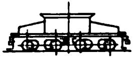
Data on Electric Locomotives of American Design

Built by the Westinghouse Electric & Mfg. Co.

					
Built for	New Haven	Grand Trunk St. Clair tunnel	Pennsylvania	New Haven	New Haven
Electric system	A.C., D.C.	A.C.	D.C.	A.C., D.C.	A.C., D.C.
Service	Passenger	Frt. & Pass.	Passenger	Frt. & Pass.	Frt. & Pass.
First placed in service	July, 1907	February, 1908	17,000-mile test	3000-mile test	Building
No. in service or on order, May, 1910	41	6	24	1	1
No. motors per locomotive	4	3	2	4	2
Armature diameter, inches	39½	30	56	39½	76
Core length, including vent opening, inches	18	14¾	23	13	13
Weight one motor, pounds	16,420	15,660	45,000	19,770	41,600
Weight all motors on locomotive	65,680	46,980	90,000	79,080	83,200
Weight all electrical parts	110,400	58,400	127,200	130,000	135,000
Weight all mechanical parts	94,100	73,600	204,800	130,000	125,000
Weight complete locomotive	204,500	132,000	332,000	260,000	260,000
Weight on driving wheels	162,000	132,000	207,800	180,000	180,000
Weight complete locomotive for A.C. operation	196,000	132,000	D.C.	241,000	240,000
Max. guar't'd speed, miles per hour	About 86	30	About 80	45	45
Feature limiting speed	Track	Armatures	Connecting rod	Armatures	Armatures
Max. tractive effort, lb.	19,200	43,800	69,300	40,000	40,000
Loco. wt. in excess of 18% adhesion Max. T. E., A. C. operation	88,700	None	None	18,500	17,500
Designed for trailing load, tons	250	500	550	1500 freight 800 pass.	1500 freight 800 pass.
Balance speed on level with above load.	About 75	About 25	60	35 freight 45 pass.	35 freight 45 pass.

DATA ON ELECTRIC LOCOMOTIVES OF AMERICAN DESIGN

Built by the General Electric Company

Built for	N. Y. C. & H. R. R.	Detroit River Tunnel	B. & O. R. R.	Great Northern	Paris-Orleans
					
Electric system	D.C.	D.C.	D.C.	3-phase	D.C.
Service	Passenger	Frt. & Pass.	Frt. & Pass.	Frt. & Pass.	Passenger
First placed in service	July, 1906	Tests completed	March, 1910	July, 1909	1899
No. in service or on order, May, 1910	47	6	2	4	11
No. motors per locomotive	4	4	4	4	4
Armature diameter, inches	29	25	25	35¾	23½
Core length, including vent opening, inches	19	11½	11½	16¼	12
Weight one motor, pounds	18,150	10,560	10,560	15,000	8,855
Weight all motors on locomotive	72,600	42,240	42,240	60,000	35,420
Weight all electrical parts	91,200	54,000	54,000	109,000	42,500
Weight all mechanical parts	138,800	146,000	130,000	121,000	67,500
Weight complete locomotive	230,000	200,000	184,000	230,000	110,000
Weight on driving wheels	141,000	200,000	184,000	230,000	110,000
Weight complete locomotive for A.C. operation	D.C.	D.C.	D.C.	230,000	D.C.
Max. guar't'd speed, miles per hour	75	30	55	30	45
Feature limiting speed	Track	Armature	Armature	Armature	Armature
Max. tractive effort, lb.	47,000	67,000	61,000	77,000	37,000
Loco. wt. in excess of 18% adhesion Max. T.E., A.C. operation	None	None	None	None	None
Designed for trailing load, tons:					
Freight		900 } on	850 } on	500 on 2.2% grade	
Passenger	435	600 } 2% grade	500 } 1½% grade		300
Balance speed on level with above load.	63	Freight 20.5 Pass. 22	Freight 26 Pass. 30	15	12

clude that, other things being equal, the higher the center of gravity, within the limits of safe operation, the better will be the high-speed tracking characteristic of the locomotive. It is not conservative, however, to assume that high center of gravity is the only method of attaining good tracking qualities. The essential feature is that the main mass of the locomotive follow the general direction of the track, and that the minimum of mass follow the slight rail irregularities. Any feature tending to this end should receive most thorough consideration, and should be condemned only when it is evident that it involves features so serious as to overshadow the desirable qualities. High center of gravity has been singled out because up to the present time it seems to be the feature which has to the greatest extent been successful in actual service.

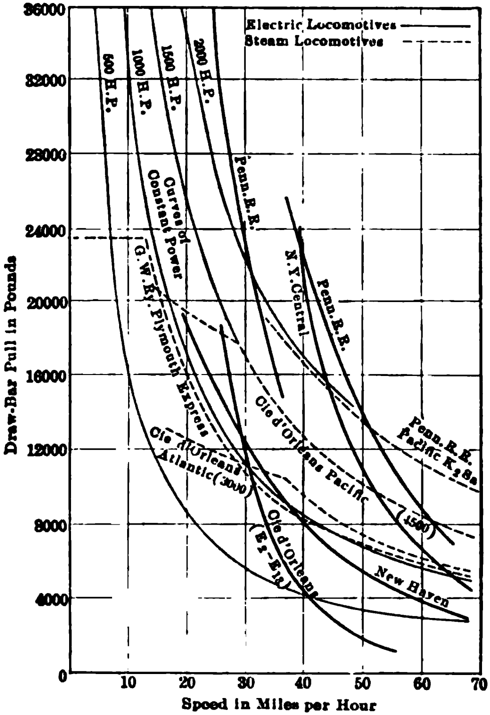
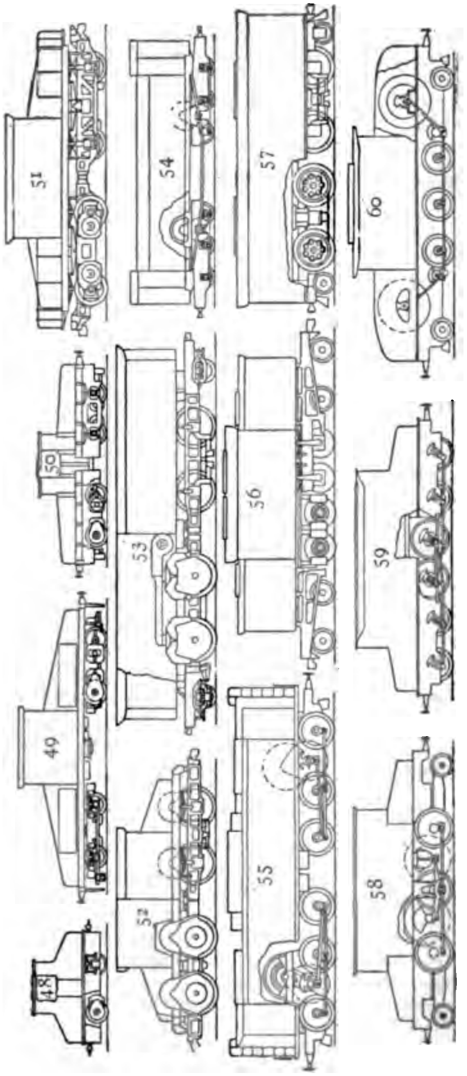
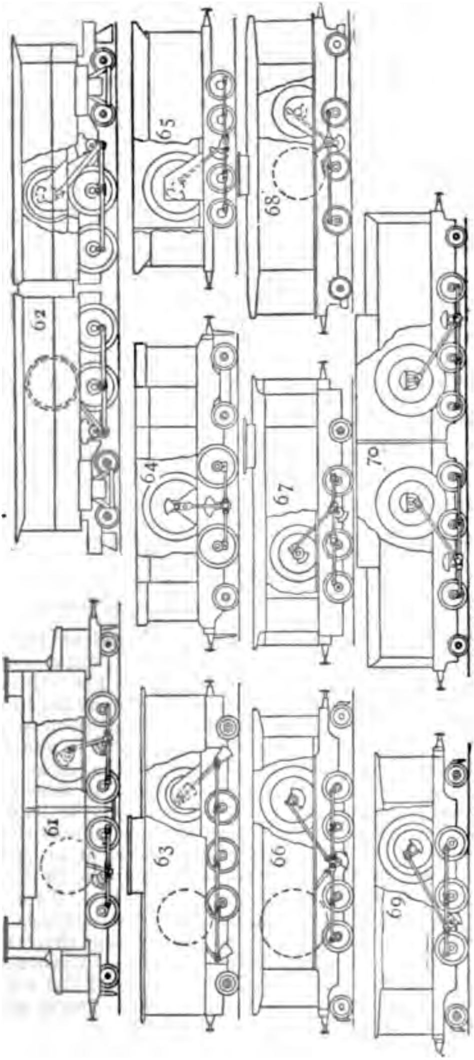


FIG. 47.—Comparative draw-bar pull, steam and electric locomotives.

The problem of weight equalization on the various wheels is closely associated with the choice of wheel arrangement. In high-speed steam locomotives for single end operation a three-point



FIGS. 48–60.—Locomotive drives—diagrams of arrangements.



FIGS. 61–70.—Locomotive drives—diagrams of arrangements (continued).

equalization, with one point leading and two points trailing, is almost universal. It is obviously a mechanical impossibility to design a stable locomotive with a three-point suspension with a single point on each end, as the three points must then be in a straight line. Thus in double end operation we are face to face with one of three things: First, running, so to speak, feathers to the front, part of the time; second, a departure from the three-point suspension; third, some automatic method of modifying the suspension so that a single point will always lead with two points trailing. The plate steel frame seems again to offer possibilities, because it can be made with some torsional flexibility, which will tend to justify a four-point equalization. In Europe many steam locomotives are made entirely without equalizing levers, the effect of equalization being secured by a rather flexible spring over each wheel, which, together with the flexibility of the plate frames, seems to give a sufficient equalization. It should be noted, however, that the European practice is radically different from our American practice in many features. The wheel weights and the track construction vary greatly, while the inspection and adjustment of machines is followed very much more closely in Europe than in this country. Some of the prominent American builders are advocating a departure from the three-point suspension in the case of large rigid frame electric locomotives. The burden of the proof evidently rests on the four-point suspension, as the steam locomotive has proven that a machine with a three-point suspension and high center of gravity will run at high speed in one direction with a surprisingly small amount of injury to the track.

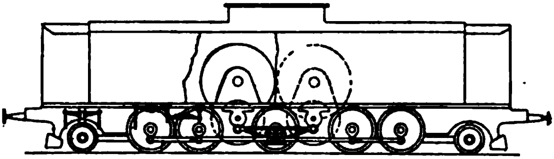


FIG. 71.—Locomotive drives, Loetschberg tunnel.

The development of the steam locomotive has shown that as higher speeds were required it became necessary to increase the diameter of the driving wheels. This increase reduces the cost of maintaining both the rolling stock and the right of way. The increase in speed meant a corresponding increase in power with added weight and, therefore, greater wheel loads. To carry this load it was necessary to have either a greater contact area between the wheel and the rail, such as is secured by large drivers, or else to have better material in the rails and the tires. Eventually both improvements were adopted and it should be noted that a continual research is in progress looking toward the production of still better materials. This saving of the track, however, was in a measure a secondary consideration, as it seems to be impracticable to operate connecting rods at more than 400 r.p.m. The high piston speed involved in a greater number of revolutions also becomes troublesome. The rough and ready rule, at present in favor, is to design the driving wheels of steam locomotives for what is termed "inch diameter speed," which means a locomotive speed of a mile per hour for every inch diameter of the driving wheels.

Only one marked difference in brake rigging between steam and electric locomotives need be noted. A greater brake-shoe pressure upon the tires is necessary in the electric locomotive than in the steam locomotive of the same weight, since in the steam locomotive most of the stored energy in the moving mass is energy of linear motion, there being only a small percentage of rotative energy stored in the wheels. But in the electric locomotive, especially if equipped with powerful geared motors with a large gear reduction, the energy of rotation is a surprisingly large percentage of the total energy stored in the moving mass, and the friction of the brake-shoes on the tires must dissipate all of this stored energy.

SECTION X

TRANSMISSION AND DISTRIBUTION

Contact Conductor, A.I.E.E. Standardization Rules

393 **Contact Conductors:** That part of the distribution system other than the traffic rails, which is in immediate electrical contact with the circuits of the cars or locomotives, constitutes the contact conductors.

394 **Contact Rail:** A rigid contact conductor.

395 OVERHEAD CONTACT RAIL: A contact rail above the elevation of the maximum equipment line.

(The contour which embraces cross-sections of all rolling stock under all normal operating conditions.)

396 THIRD RAIL: A contact conductor placed at either side of the track, the contact surface of which is a few inches above the level of the top of the track rails.

397 CENTER CONTACT RAIL: A contact conductor placed between the track rails, having its contact surface above the ground level.

398 UNDERGROUND CONTACT RAIL: A contact conductor placed beneath the ground level.

399 GAGE OF THIRD RAIL: The distance, measured parallel to the plane of running rails, between the gage-line of the nearer track rail and the inside gage-line of the *contact surface* of the third rail.

400 ELEVATION OF THIRD RAIL: The elevation of the contact surface of the third rail, with respect to the plane of the tops of running rails.

401 STANDARD GAGE OF THIRD RAILS: The gage of third rails shall be not less than 26 in. (66 cm.) and not more than 27 in. (68.6 cm.).

402 STANDARD ELEVATION OF THIRD RAILS: The elevation of third rails shall be not less than 2¾ in. (69 mm.) and not more than 3½ in. (89 mm.).

403 THIRD RAIL PROTECTION: A guard for the purpose of preventing accidental contact with the third rail.

404 **Trolley Wire:** A flexible contact conductor, customarily supported above the cars.

405 **Messenger Wire or Cable:** A wire or cable running along with and supporting other wires, cables or contact conductors.

A primary messenger is directly attached to the supporting system. A secondary messenger is intermediate between a primary messenger and the wires, cables or contact conductors.

406 **Classes of Construction:** Overhead trolley construction will be classed as *Direct Suspension* and *Messenger or Catenary Suspension.*

407 DIRECT SUSPENSION: All forms of overhead trolley construction in which the trolley wires are attached, by insulating devices, directly to the main supporting system.

408 MESSENGER OR CATENARY SUSPENSION: All forms of overhead trolley construction in which the trolley wires are attached, by suitable devices, to one or more messenger cables, which in turn may be carried either in *Simple Catenary, i.e.*, by primary messengers, or in *Compound Catenary, i.e.*, by secondary messengers.

409 SUPPORTING SYSTEMS shall be classed as follows:

410 SIMPLE CROSS-SPAN SYSTEMS: Those systems having at each support a single flexible span across the track or tracks.

411 MESSENGER CROSS-SPAN SYSTEMS: Those systems having at each support two or more flexible spans across the track or tracks, the upper span carrying part or all of the vertical load of the lower span.

412 BRACKET SYSTEMS: Those systems having at each support an arm or similar rigid member supported at only one side of the track or tracks.

413 BRIDGE SYSTEMS: Those systems having at each support a rigid member supported at both sides of the track or tracks.

414 STANDARD HEIGHT OF TROLLEY WIRE ON STREET AND INTERURBAN RAILWAYS: It is recommended that supporting structures shall be of such height that the lowest point of the trolley wire shall be at a height of 18 ft. (5.5 m.) above the top of rail under conditions of maximum sag, unless local conditions prevent. On trackage operating electric and steam road equipment and at crossings over steam roads, it is recommended that the trolley wire shall be not less than 21 ft. (6.4 m.) above the top of rail, under conditions of maximum sag.

Overhead Trolley Construction

The following notes on overhead trolley construction are principally taken from the Recommended Specifications of the American Electric Railway Engineering Association.

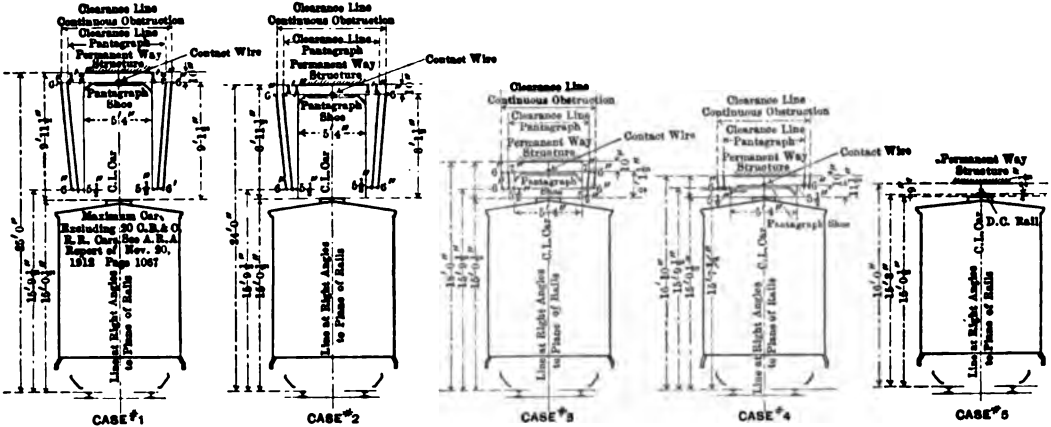
Classes. Overhead trolley construction may be classed as (a) direct suspension, (b) catenary suspension. Direct suspension comprises construction in which the trolley wires are attached, by suitable devices, directly to the main supporting system. Catenary suspension comprises construction in which the trolley wires are attached, by suitable devices, to one or more messenger cables which in turn are carried (a) in simple catenary, by main supporting system; or (b) in compound catenary, by secondary messengers which in turn are carried by the main supporting system.

Supporting systems for direct or catenary suspension may be classed as:

(a) Simple span, comprising those systems having at each point of support a single flexible member attached at both sides of the track or tracks.

(b) Compound span, comprising those systems having at each point of support two or more flexible members attached at both sides of the track or tracks, the upper member carrying part or all of the vertical load of the lower member.

Bracket, comprising those systems having at each point of support an similar rigid member attached at one side only of the track or tracks.


Clearance Line Continuous Obstruction
Clearance Line Pantagraph
Permanent Way Structure
Contact Wire
Pantagraph Shoe
5'4"
9'11½"
C.L.Car
Maximum Car, Excluding 20 O.B.& O. R.R. Cars See A.R.A. Report of Nov. 20, 1912 Page 1067
Line at Right Angles to Plane of Rails
25'0"
15'9"
15'0"
24'0"
16'10"
16'0"
12'7¾"
D.C. Rail
CASE #1
CASE #2
CASE #3
CASE #4
CASE #5

CLEARANCE FOR TRAINMAN WITH LANTERN

ASSUMPTIONS

REACH OF SIX FOOT TRAINMAN 7'8"
LANTERN SWING 1'0"
CLEARANCE 0'5½"
TOTAL DISTANCE CAR RUNNING BOARD TO WIRE 9'1½"

CLEARANCE FOR TRAINMAN WITHOUT LANTERN

ASSUMPTIONS

REACH OF SIX FOOT TRAINMAN 7'8"
CLEARANCE 0'5½"
TOTAL DISTANCE CAR RUNNING BOARD TO WIRE 8'1½"

NORMAL MINIMUM CLEARANCE WITHOUT TRAINMAN ON CARS

ASSUMPTION

NORMAL DISTANCE CAR RUNNING BOARD TO WIRE 2'1½"

SPECIAL MINIMUM CLEARANCE WITHOUT TRAINMAN ON CARS

ASSUMPTION

MINIMUM DISTANCE CAR RUNNING BOARD TO WIRE 0'11½"

MINIMUM CLEARANCE D.C. OVERHEAD

ASSUMPTION

MINIMUM DISTANCE CAR RUNNING BOARD TO RAIL 0'2½"

NOTES

Momentary Obstructions such as Signal Blades may approach Pantagraph Clearance Line.

Sway of Pantagraph Based on One Inch Difference in Hight of Car Springs, One-half Inch Difference in Elevation of Track Rail, and Sway of Six Inches Either Side at Twenty-two Feet above Top of Rail for Pantagraph Itself.

These Diagrams show Minimum Clearances: Additional Clearances will be Required to Provide for Special Features of Design. Sag between Points of Support as Affected by Length of Span and Temperature Changes, and also for Steady Strains, Pull Offs etc., if any.

All Hights to be Measured at Right Angles to Plane of Rails at Center Line of Track.

FIG. 1.—Diagram of clearances for overhead working conductors. A.E.R.E.A. recommended design.

(*d*) Bridge, comprising those systems having at each point of support a rigid member attached at both sides of the track or tracks.

Supporting structures are the devices which sustain the supporting system, and may be poles, whether of wood, steel, or concrete, towers, buildings, trees, or any other form of support, together with their anchors, guys, braces and similar reinforcing attachments. The type of supporting structure will be governed largely by local conditions. In general, natural wood (or concrete) poles are used for all interurban construction and wherever else practicable; steel poles may be used in streets if so desired; sawed poles and tree attachments should not be employed, and building attachments should be used only when local authorities compel such use, in which case special precautions and construction will be necessary. (See page 294.)

Pole Framing. Before setting, wood poles should be roofed, butts squared, entire pole rough shaved, knots smoothed, gains and faces made, and roof, gains and faces given a coat of preservative or paint. The size, number and location of holes, faces and gains vary. In general: holes, unless specifically noted otherwise, should be of same size as bolt or rod for which intended. Faces should be of sufficient area and of proper shape to receive their fittings, and should have about ¼ in. margin outside; they should be slightly hollowed to prevent rocking of fitting. Gains should be square with axis of pole, ¾ in. minimum depth, of width to secure snug fit of arm, and slightly hollowed to prevent rocking. The roof should have a pitch angle of 45 deg. and should be either a wedge with edge parallel to line when pole is set, or a cone.

Pole Clearances. On private right of way and elsewhere when practicable, side supports should be set with a minimum clear distance of 7 ft. 6 in. from center line of track to face of support at level of top of rail, and center supports should have a minimum clearance of 7 ft. from center of track, this clearance to be increased if necessary on curves to allow for rail elevation and car overhang. Where curb lines are established, poles should be set just behind the curb itself unless local ordinances or conditions prescribe other location.

Pole Spacing. Poles on tangents should be normally spaced not less than 90 ft. and not more than 110 ft. apart. Poles on curves should be set as nearly as practicable in accordance with the table on page 601.

Pole Setting—Depth of Holes. Pole holes in level ground should have depths as follows:

	Depth of hole	
Length of pole (feet)	In rock or concrete	In earth
30	5 ft. 0 in.	6 ft. 0 in.
35	5 ft. 6 in.	6 ft. 0 in.
40	5 ft. 6 in.	6 ft. 6 in.
45	6 ft. 0 in.	6 ft. 6 in.
50	6 ft. 6 in.	7 ft. 0 in.
55	6 ft. 6 in.	7 ft. 6 in.
60	7 ft. 0 in.	8 ft. 0 in.
65	7 ft. 0 in.	8 ft. 6 in.
70	7 ft. 0 in.	9 ft. 0 in.

In very compact soil pole holes may have depths intermediate between those for same lengths in rock or concrete, and in earth.

The depth of a hole on sloping ground should be measured from the lower side of the hole; and in very steep slopes and in loose or otherwise doubtful material the depth should be increased over the standard depth by an amount to be determined for each case on the ground.

Barrel Holes. In material which caves freely one or more barrels or the like may be used as casing, and driven down as the material is dug from inside. Such barrels or casings may be of wood or steel and should be of sufficient size to give clear tamping room of at least 6 in. around the pole without cutting the latter.

Rake. Wood poles with brackets should in general have a rake from the track of 6 in. in 24 ft.; steel poles with brackets, of 3 in. in 24 ft. Wood poles with span should have a rake from the track of 12 in. in 24 ft.; steel poles with span should have a rake from track of 6 in. in 24 ft. When the strain is from the track, as with poles on the inside of a curve, brace poles or head guys should be used, and standard rake maintained. Double bracket poles should be set without rake; other poles between tracks, and poles under outside jurisdiction may be so set if necessary or required.

Keys. All span poles as well as bracket poles on curves of radius less than 2400 ft., and such other poles as may be designated because of unusual load conditions, should be provided with suitable keys of wood, stone, or concrete, at least 4 in. thick with a cross-section not less than 32 sq. in. One key 2 ft. long should be placed on edge behind the pole at the bottom of the hole; the other key 4 ft. long should be placed on edge in front of the pole just below the surface of the ground.

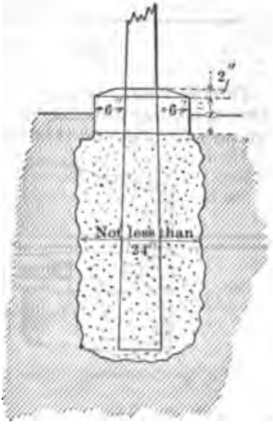


FIG. 2.—Concrete pole setting.

Refilling Holes. In setting poles the excavated material, if suitable, should be replaced in thin, even layers, and firmly and thoroughly tamped, not more than one shoveller serving three tampers, until the hole is completely filled, after which the earth should be well packed around the pole in a small mound, and if on a slope there should be made on the lower side, a berm at least 6 ft. wide from pole to edge. In rock holes the broken rock should be used to thoroughly wedge the pole in place. Black loam and similar poor material should be replaced by suitable material.

Concrete Settings. Poles subject to heavy lateral strains which cannot well be met by guying or bracing may be set in concrete mixed wet and consisting of one part Portland cement, three parts clean sharp sand, and five parts good hard gravel or broken stone of size to pass screen with holes 2 in. diameter, and to be retained by screen with holes ¾ in.

diameter. Concrete settings should have a diameter at least 12 in. greater than that of the pole, and should completely fill pole hole to a level 6 in. below surface of the ground. In parking strips the authorities may require the concrete to finish at this level, but such latter practice is undesirable. Wherever practicable the concrete should be finished as indicated in Fig. 2. See also page 781.

Span Wires Attached to Buildings. Building owners in crowded districts sometimes prefer to have span wires attached to their buildings rather than to have poles in front of the buildings. Eye bolts for the purpose are sometimes placed in the building during construction. As a means of suspension such an arrangement is satisfactory but it must be borne in mind that it subjects the building to unusual strains and the wires are more dangerous in case of breakage as they are over the sidewalk and will sweep it with more force than when attached to poles.

Span and Guy Attachments. Span and guy attachments may be made up with such of the following forms as may be desired:

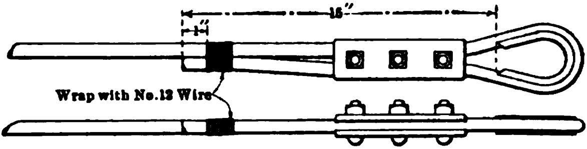


FIG. 3.—Thimble end attachment.

Thimble End. (Fig. 3.) Thimble end may be made by bending strand around thimble of proper size. The strand end should extend 15 in. beyond thimble, and should be secured by a three bolt clamp close to thimble, and by a serving of about 10 turns of No. 12 galvanized wire 1 in. from end of strand.

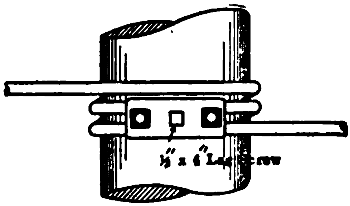


FIG. 4.—Three-bolt clamp hitch.

Two-turn Wrap. Two-turn wrap may be made by taking strand around pole twice. If at end of span or guy, the end of the strand should extend 30 in. beyond the face of pole and should be secured to main part by a three bolt clamp 15 in. from face of pole and by a serving of about 10 turns of No. 12 galvanized iron wire 1 in. from end of strand. If hitch is at an intermediate point in span or guy it should be secured by a three bolt clamp on the outside parts of the strand, the center bolt of clamp being replaced by a lag screw into the pole as shown by Fig. 4.

Close Tie (Fig. 5.) Close tie may be made by bending strand tightly around attachment, leaving a free end about 15 in. long. One wire of this end should be unlayed back to the attachment and served on main part and remainder of end; the other wires should be in turn unlayed back to the last wrap and served over main part and remainder of end until latter is all served on.

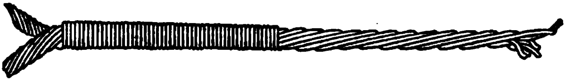


Fig. 5.—Close tie.

Temporary Tie. (Fig. 6.) Temporary tie may be made like permanent tie of same kind, but end should be left long enough to allow for adjustment and permanent make up and should be secured to main part by one or more servings of wire. In making temporary ties bend should be of as large radius as possible until permanently secured.

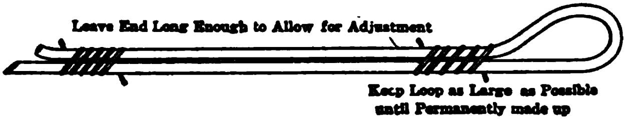

Leave End Long Enough to Allow for Adjustment
Keep Loop as Large as Possible until Permanently made up

Fig. 6.—Temporary tie.

Anchors. (Fig. 7.) Anchors in earth should consist of a wooden deadman 4 ft. long, at least 6 in. thick, and having a cross-section not less than 48 sq. in., buried at least 4 ft. below the surface with not less than 2 ft. of rock if reasonably obtainable well packed into hole, and the earth filling above thoroughly tamped. The anchor should pass through center of deadman, and must lie in line of pull of guy to prevent bending. Patent anchors of holding capacity equal to the breaking strain of the strand to be used with them, and having rugged parts sufficiently large to allow a reasonable amount of corrosion without reduction in holding capacity, may be used in place of rod and deadman where conditions are favorable. Anchors in rock should consist of eye-bolt securely leaded or sulphured for entire length of shank in hole inclined at right angles to pull of guy. In rock of sufficient strength to safely withstand the action, mechanical wedge type eye-bolts may be used, and the lead or sulphur omitted. Where practicable guys may be anchored to adjacent pole at point not less than 7 ft. above ground.

Guys. (Fig. 7.) Guys should be used where practicable on wood poles on curves of radius less than 900 ft., on poles to which are attached strain plate guys, trolley guys and head guys; and wherever any side strain exists. They should be of galvanized seven-wire steel strand with thimble end at anchor attachments, and two-turn wraps at proper height for attachment. The lead or horizontal distance from pole at ground line to guy at same level, whenever practicable, should be equal to the distance from ground line at pole to guy wrap. Guys located where there is a liability of persons or animals running into them should be made conspicuous by a piece of pipe 2 or more inches in diameter and 6 ft. long, slipped over guy, resting on anchor rod eye and painted white. Where guy is already installed, a wooden casing, 3 in. diameter or square and 6 ft. long, may be used in place of the pipe. The halves should be well white leaded, and should clamp the guy tightly when screwed together, the bottom resting on anchor-rod eye. Guy hooks attached one on each side of pole at level of guy wrap by a ⅝-in.

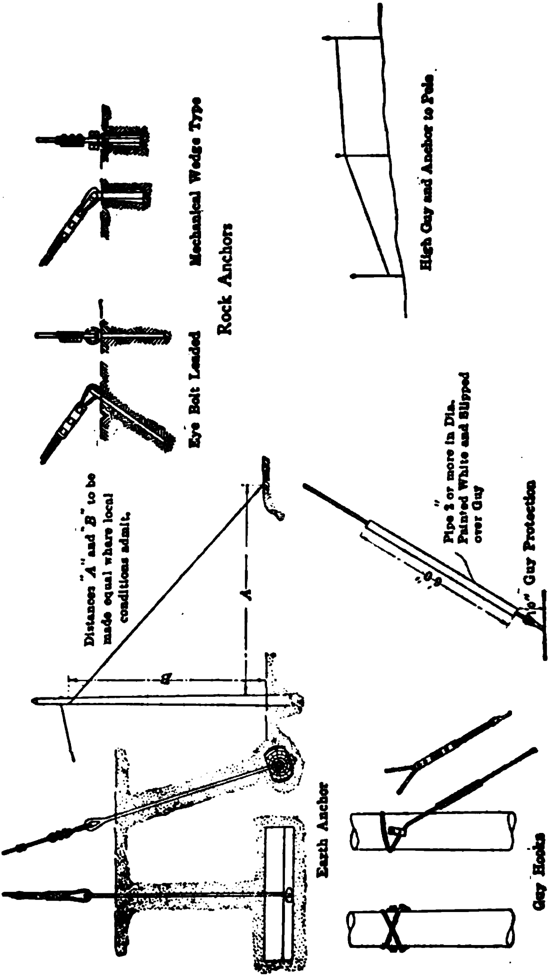

Eye Bolt Leaded
Mechanical Wedge Type
Rock Anchors
High Guy and Anchor to Pole
Distances "A" and "B" to be made equal where local conditions admit.
A
B
Pipe 2" or more in Dia. Painted White and Slipped over Guy
6'0"
10" Guy Protection
Earth Anchor
Guy Hooks

FIG. 7.—Methods of attaching guys to poles and attachments.

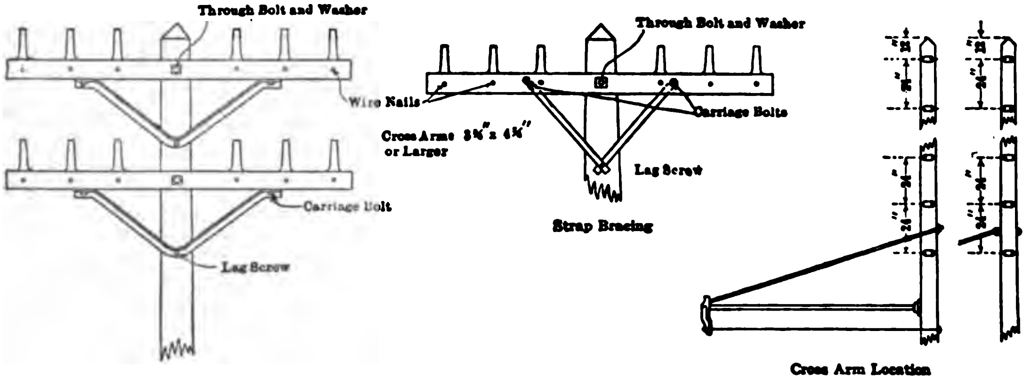
through-bolt at right angles to line of pull should be used where local conditions compel the use of a lead less than one-fourth the distance from ground line at pole to guy wrap. Where guys cannot be run directly to secure attachments they may be carried high on adjoining poles to a point where anchorage can be obtained.

Cross-arms. (Fig. 8.) Cross-arms should be given one coat of perservative or two coats of paint before pins are installed. Pin shanks should be dipped in the preservative or paint, and while wet firmly seated in hole and secured by a wire nail 2 in. long driven through side of arm into pin. All cross-arms should be held to pole by a through-bolt driven from back of pole toward and through arm, having a washer at each end, with hole at back of pole properly counterbored to secure good seat for washer. Cross-arms 3¼ in. wide by 4¼ in. deep should be steadied by strap braces secured to pole by a lag screw, and to side of arm away from pole by carriage bolts on center line of arm with nuts next to the braces. Arms up to and including 48 in. in length should have braces 24 in. long, fastened to arm 16 in. from center; arms over 48 in. long should have braces 28 in. long, fastened to arms 19 in. from center. Cross-arms of section heavier than 3¼ by 4¼ in. should be steadied by an angle brace, fastened to bottom of arm by carriage bolt and to pole by a through-bolt. The lowest feeder, telephone or signal cross-arm should have its center not less than 21 ft. above top of rail; other feeder, telephone or signal cross-arms should be spaced at least 24 in. from center to center. If the pole also carries a transmission line there should be a clear distance of at least 6 ft. between the top feeder, telephone or signal arm and the lowest transmission arm. Double arms for feeder should be used at ends of curves and on intermediate poles of curves of radius less than 500 ft. Double arms must be parallel at the same height. Both arms should be fastened to the pole by the same through-bolt, and should be firmly tied together by spacing bolts with nut and washer each side of each arm, located on the center line of arm, 8 in. from end.

Choice of Supporting System. Bracket support on side poles should be used for all single track where local conditions do not prevent, except for curves of radius less than 300 ft. Bracket support on central poles may be used on double track where practicable. Span support should be used on single track for curves of radius less than 300 ft. and where local conditions do not permit use of brackets; on double track, including turnouts, not employing central bracket poles; and for more than two tracks. Compound spans should be used when necessary to support the overhead of a series of tracks too closely spaced to permit poles between. Bridge support will be used only in special cases.

Height of Trolley. Supporting structures should be of such height that the trolley wire in streets and on interurban lines will be at a height of not less than 18 ft. above the top of rail unless local conditions prevent; on trackage operating electric and steam road equipment and at crossings over steam roads the trolley wire should be not less than 21 ft. above the top of rail.

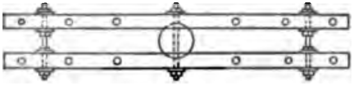
Brackets. Brackets should be of sufficient length to allow 8 in.



Cross Arm and Pin Angle Bracing

Strap Bracing

Cross Arm Location



Double Cross Arms

FIG. 8.—Cross-arm attachments.

between hanger or strain insulator and the end casting. When poles are on outside of curve the length of bracket should be sufficient to allow for effect of pole rake and rail elevation. The eye-bolt should be installed at level of trolley wire; the pole casting with center a distance above center of eye-bolt equal to distance center to center between span eye and arm socket of end casting; and the oversupport rod a distance in inches above pole casting of three times the length of arm in feet. On wood poles eye-bolts and oversupport rod should pass through pole and pole casting should be attached by two lag screws. On steel poles, eye for strand, socket for arm and pole attachment for oversupport rod should be carried by special fittings, clamping to pole. Eye-bolt should be installed pulled out to full length; the nut, on wood pole, seated against a washer; the arm should be given an upward rake from the horizontal of 1 in. in 4 ft. of length; the intermediate casting should be clamped on arm so that trolley wire comes midway between it and end casting; and the steel strand should be close tied into eye-bolt and into end castings with 2 in. of slack to permit hanger installation. On steel poles strain insulators should be cut into strand on either side of hanger, and between end and intermediate castings, to give double insulation. Brackets on curves should be installed as on tangents except that pull-over with attached strains should be close tied in strand in approximately correct position, but ties at eye-bolt and end casting should be temporary until final dressing of overhead.

Spans. Spans should consist of seven-wire strand, and in case of steel poles, should have strain insulator cut in not less than 5 ft. from pole; where pole carries high tension circuits, a strain insulator should be used of suitable strength and creeping surface. Where a foreign line crosses close to the span two strain insulators should be used, one at either side of foreign line, to ensure that if latter falls it shall be on a dead section. Spans on tangents should be close tied into eye-bolts at height above trolley wire not more than one-tenth the distance from track center to pole but in no case should the factor of safety for the span wire be less than two under the conditions to be expected. On wood poles eye-bolts should be at least 12 in. below top of pole, and should be installed at full length, seated against washers. Spans on curves should be installed as on tangents except that pull-over with attached strains should be close tied in strand in approximately correct position and temporarily tied in eye-bolts until the final dressing of overhead. In case of two or more tracks, strand between pull-overs should have temporary tie at one end until final dressing.

Trolley Wire. Trolley wire may be run out by mounting the reel on an arbor on which it can freely turn, and leading the wire to an anchor or to trolley already installed. Tension may be maintained by a brake on rim or side of reel, but under no circumstances should braking be done against the copper. The wire should be pulled to correct sag and temporarily tied to brackets or spans by rope or other soft insulating ties. Particular care should be taken to prevent twisting, kinking or bruising the wire. Parallel faced clamps should be used; chains, cam come-alongs or other short grip devices should not be employed. The sags should be as follows, and in pulling up great care should be taken that the corresponding tensions are not exceeded:

SAG AND TENSION OF TROLLEY WIRE (100 FT. SPANS)

Temperature, deg. F.	Size of Wire							
	0		00		000		0000	
	Sag, in.	Tension, lb.	Sag, in.	Tension, lb.	Sag, in.	Tension, lb.	Sag, in.	Tension, lb.
0	2½	1920	3	2020	2¾	2780	2¾	3500
30	3	1600	3½	1730	3¼	2350	3¼	2960
60	3½	1370	4¼	1420	4¼	1800	4¼	2260
90	4½	1070	5½	1100	5¼	1450	5¼	1830
120	6	800	7¾	760	7¼	1050	7¼	1330

The table values are for spans of 100 ft.; for any other span the sag for the tension given in the table is as the squares of the lengths. For example, for span of 50 ft., the sag for a given temperature is equal to 50 squared divided by 100 squared, or one-quarter the corresponding table value for that temperature.

After the trolley wire has been temporarily tied up with the proper sags, and the line has been anchored, the line ears and hangers may be accurately located and attached, clinch ears being thoroughly closed down to give secure grip and smooth running surface, and the mechanical ears well seated in grooved wire, the clamp screws then being slightly upset to prevent backing out.

Trolley Wire Splices. Splices should be of a type to develop full strength of trolley wire, and should be so installed as to offer the least possible obstruction to the passage of trolley wheel. Grooved wire should be kept in perfect alinement, and if the splice is of the soldering type, it should be thoroughly sweated on without annealing the wire. In any case the free ends of the wire should be bent sharply back at the outlet, and cut off forming a hook with end ½ in. long.

Trolley Wire Guys. In bracket construction trolley wire guys should be installed at the ends of curves and on long curves and tangents at equal intervals as nearly as possible, but not to exceed 1500 ft. apart. Trolley wire guys should be seven-wire steel strand attached to strain plate supported at a bracket by double pull-over with proper insulation and led both ways to next adjacent poles. Each guy should have a strain insulator cut in it 5 ft. from the strain plate, and should be secured to proper pole by a two turn wrap at height of bracket arm. Where practicable, the strain of these guys should be taken by anchor guys in the line of the pull; if this is impracticable, high guys should be used. Great care should be taken to ensure equal pulls on the guys, and especially that the strain plate is not twisted out of line; the ties should not be made up permanently until the final dressing of the overhead.

Curves. (Fig. 9.) Curves should be made up with straight line clinch ears for round wire, or double clip mechanical ears for grooved wire, attached to suitably insulated pull-over bodies. Support should be by span except where rest of line is in bracket and radius is greater than 300 ft. Between supports curves should be held to line by seven-wire steel strand, with single body pull-offs for single track or for outside one of several tracks, and double body pull-offs elsewhere, spaced as follows:

Radius of curve (feet)	Spacing of pull-offs (feet)	Number of pulls between supports	Distance apart of poles (feet)
40	7	4	35
50	8	4	40
60	9	4	45
70	10	4	50
80	11	4	55
90	12	4	60
100	13	4	65
125	14	4	70
150	15	4	75
200–500	20	3	80
750	25	3	100
1000	33⅓	2	100
1500–2000	50	1	100
Above 2000	100	0	100

The pull-overs in each span should have bodies and strains held radially to curve by a lacing of seven-wire steel strand at least 6 in. away from trolley wire, which lacing, however, may be omitted from any pull making an angle of 60 deg. or more with the ear to which it is attached. With an odd number of pull-over bodies the middle one should have pull-off strand to each pole. Intersections and complicated special work, particularly in city streets, will usually require special and individual study and treatment. Figs. 10 to 16, inclusive, give typical overhead layouts for such special work.

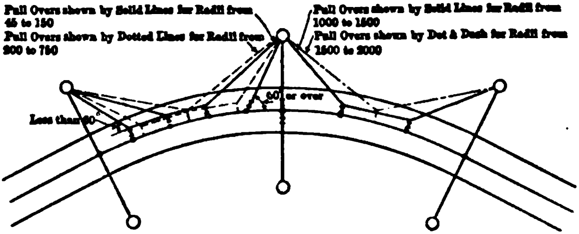

Pull Overs shown by Solid Lines for Radii from 45 to 150
Pull Overs shown by Dotted Lines for Radii from 200 to 750
Pull Overs shown by Solid Lines for Radii from 1000 to 1500
Pull Overs shown by Dot & Dash for Radii from 1500 to 2000
60° or over
Less than 60°

FIG. 9.—Location and arrangement of pull-offs in trolley wire curves.

Offset of Trolley on Curves. Curves should be dressed with uniform deflection at pull-overs and should offset to the inside of curve an amount given by the expression

$$S = \frac{EH}{G} + R - \sqrt{R^2 + P^2 - Q^2 - L^2}$$

in which

S = radial offset of trolley wire toward center of curve
E = super-elevation of outer rail

H = height of trolley wire above rail
G = track gage
R = radius of curve
P = distance from center of car to pivot of trolley base
Q = distance from center of car to center of truck
L = horizontal distance from pivot of trolley base to point of contact between trolley wheel and trolley wire.

NOTE: All values in terms of feet.

The total offset should be uniformly tapered off from full value at inside easement point of track to no offset at outside easement point. If track is not eased, start with full offset at distance inside end of curve as given below, and run to no offset at point at equal distance outside end of curve.

Radius of curve	Start offset easement
Up to 110 ft.	20 ft. from end of curve
100 to 500 ft.	40 ft. from end of curve
500 to 1000 ft.	60 ft. from end of curve
Above 1000 ft.	100 ft. from end of curve

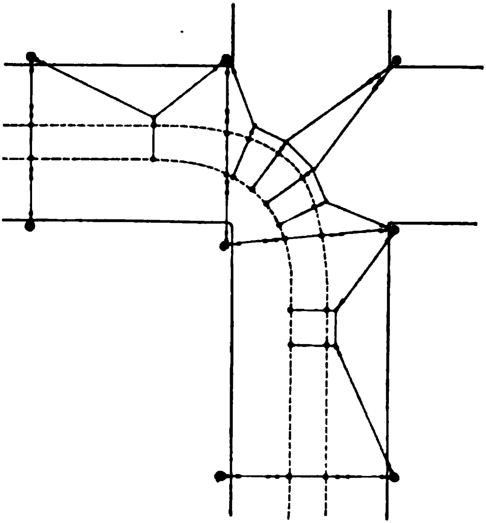


FIG. 10.—Trolley on double-track curve.

Frogs. Frogs should be installed with both main line and branch trolley wires led straight through, the latter to end 6 ft. beyond frog in eye of strain insulator, to other end of which is close tied a seven-wire steel strand, secured to pole at a level as nearly that of frog as will allow safe clearance over other wires. The frog itself should be held on each side by a guy of seven-wire steel strand with an insulator attached to frog and secured to proper poles at the

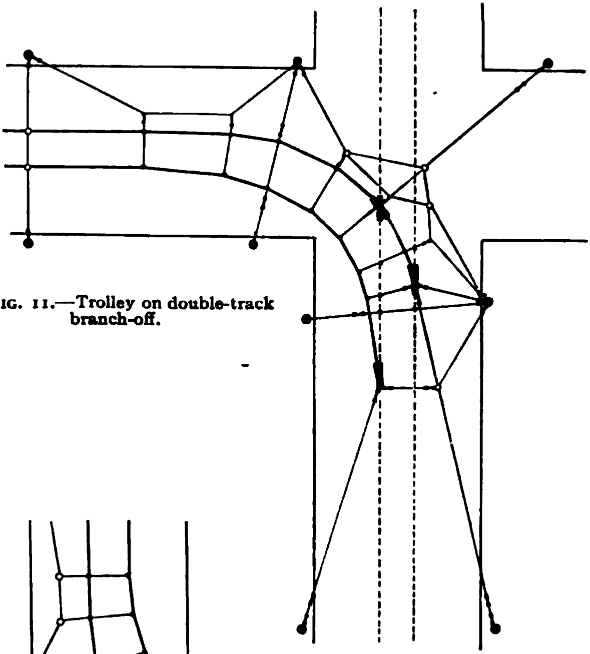


Fig. 11.—Trolley on double-track branch-off.

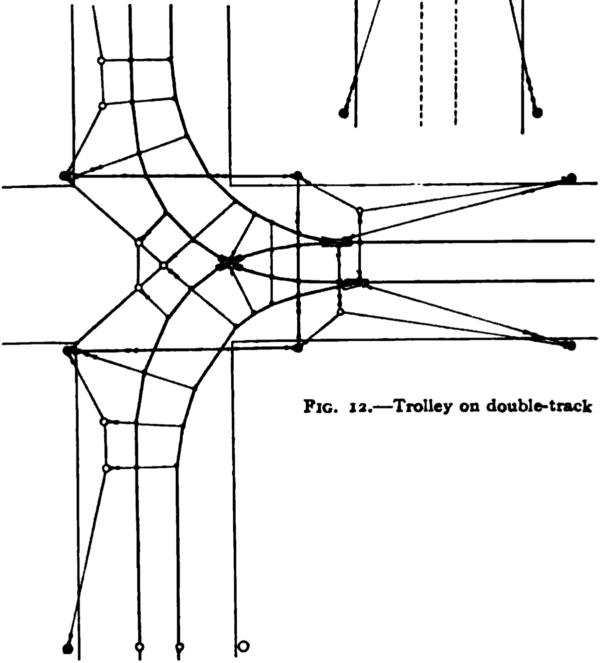


Fig. 12.—Trolley on double-track Y.

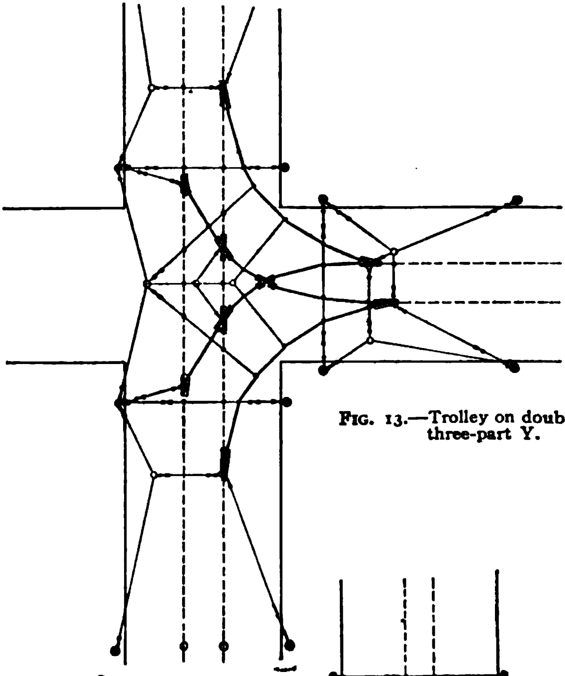


FIG. 13.—Trolley on double-track three-part Y.

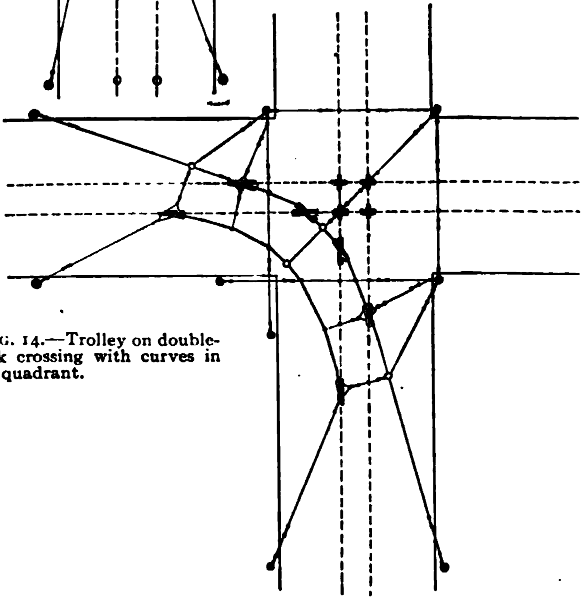


FIG. 14.—Trolley on double-track crossing with curves in one quadrant.

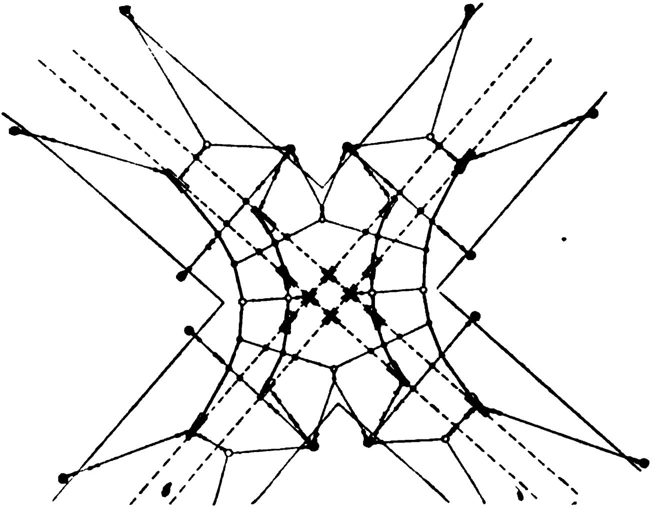


Fig. 15.—Trolley on double-track crossing with curves in opposite quadrants.

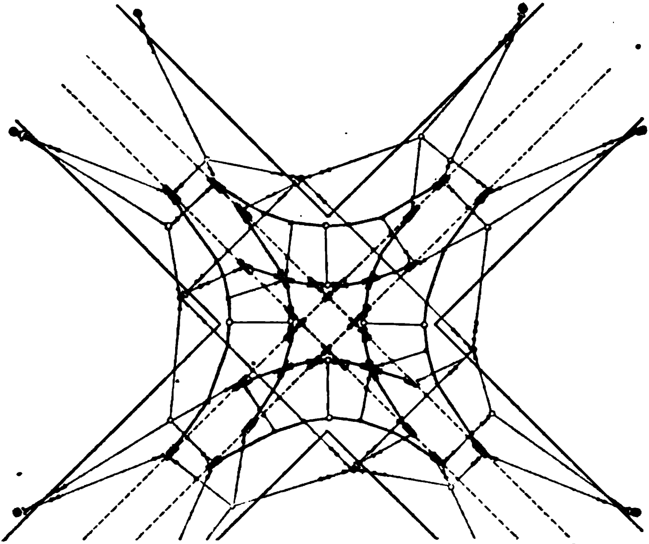


Fig. 16.—Trolley on double-track crossing with curves in four quadrants.

point of span attachment. Frogs should be temporarily located on center line of main track and one-third distance from track switch points to track frog point back from track switch points, and if need be should be shifted to suit local conditions and equipment. Until final location is made, trolley wire should be clamped just firmly enough to prevent slipping without bruising or kinking. Care must be taken that frog is not located too far back of track switch points, as such location, while often giving satisfactory running, will result in excessive wear of trolley wire.

Crossings. Crossings wherever practicable should be installed without cutting either of the line wires, which latter should be clamped just firmly enough to prevent slipping without bruising or kinking until the crossing has been satisfactorily located. Where wire must be cut, at least 3 ft. of free end should be left outside clamp until the final adjustment, after which the end should be cut off close to the clamp.

Feed Taps. (Figs. 17 and 18.) Feed taps should be at points of support and should consist of proper size triple braid, weatherproof stranded connection from feeder, feed yoke well soldered on at proper point, and straight line ear soldered to the trolley wire and bolted to the yoke. In general, feed taps should be located every 1000 ft. With bracket support the feeder connection should run from the feeder to which it should be well soldered, to strain attached to span eye-bolt in pole, thence, replacing the usual steel strand through insulated intermediate casting to strain attached to end casting of bracket. Bracket tube should be of sufficient length to allow at least 8 in. of connection cable between feed yoke and end strain. and intermediate casting should be so located that feed yoke ay between it and end casting. With span support the

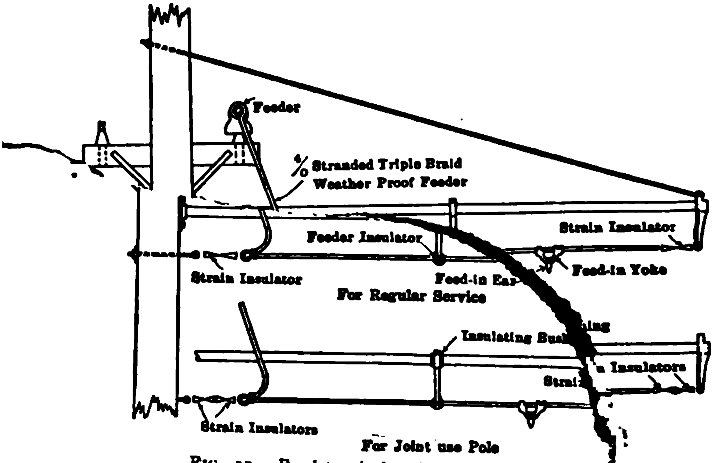


FIG. 17.—Feed tap in bracket construction.

feeder connection should run from feeder to strain attached to span eye-bolt in pole, thence, replacing the usual steel strand, to close tie in strain 5 ft. beyond trolley farthest from feeder. Span should be completed by seven wire steel strand close tied into strain and into pole eye-bolt, and should sag not greater than one-tenth the distance from trolley wire to pole.

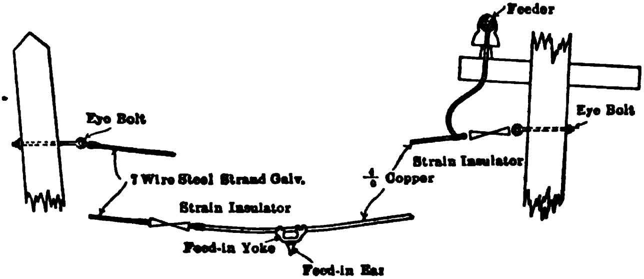


FIG. 18.—Feed tap in span construction.

Feed wire may be run out by mounting the reel on an arbor on which it can freely turn, and if practicable, run along the line on a car or wagon. Where local conditions necessitate pulling feeder on end over the cross-arms, great care must be taken to prevent injury, especially to insulated feeder, rollers or snatch blocks of ample size being used at each arm. Feeder should be strung, for spans of 100 ft., with sags not less than those of the following table:

ALLOWABLE SAGS IN FEEDERS FOR DIFFERENT TEMPERATURES

Temperature, Fahrenheit (degrees)	Copper (in.)	Aluminum (in.)
0	10	5
30	13⅓	10
60	17	16
90	20⅓	21½
120	23½	26

The table values are for either bare or weatherproof feeder of any size from 0000 to 2,000,000 circular mils. For spans other than 100 ft. in length the sag should be in the same ratio to the table values as is the square of the span to 100 squared.

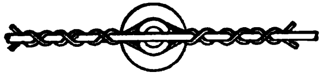


FIG. 19.—Top tie for feeder.

Feeder should be installed in the top groove of the insulator on tangents and in the outer side groove on curves and at angles, and should be tied in with No. 6 soft drawn wire of the same metal as feeder. Top tie (Fig. 19) may be made with two tie wires each 15 in. long. The first wire should be looped around insulator in side groove, the ends crossed and twisted once under cable, then brought up, one each side and wrapped around cable, crossing above and matic or hand-operated sectionalizing switch is used, tests should be made periodically to determine any changes necessary in feeder sizes in order to divide the load properly between the feeders.

Lightning arresters where required by local conditions should be installed at feed taps, just below the feeder cross-arm, and should be connected to the feed tap close to its attachment to the feeder by solid insulated No. 4 copper wire. The ground wire should be of solid insulated No. 4 copper wire, stapled to the back of pole and either (*a*) extended as a ground coil, (*b*) well soldered into a pipe ground or (*c*) well soldered to the track rails. In any case the lower portion should be protected by a wood molding 8 ft. long with groove ¼ in. square in one side, well painted on all sides with paint or other preservative. With ground coil or grounding pipe the lower end should extend 1 ft. below the surface of the ground; with rail connection the ground wire should make a large easy bend and should have some form of wooden protection up to its attachment to the rail to guard against injury when tamping. Lightning arrester grounds may be attached to the track rails or to an earth ground, but in no case should an arrester be grounded in both ways. Earth grounds should be secured as follows: Where permanently moist earth is assured at reasonable depth the ground may consist of ½-in. pipe driven at least 3 ft. into the moist earth. Where there is doubt as to the condition of the soil, excavate. If permanently moist earth is reached, install pipe ground; if otherwise, install a flat coil containing 40 lin. ft. of solid No. 4 bare copper wire imbedded in not less than 7 cu. ft. of charcoal. Particular care must be taken to ensure that the ground is effective; unless a good ground is secured the arrester cannot give protection.

Soldering. Where soldering is necessary, it should be done with non-corrosive paste or with stearin; the use of acid or corrosive salts should be strictly forbidden; and great care should be taken to prevent overheating and annealing.

Linemen. Only such men should be employed on overhead construction as have had experience and are so skilled in the work that those details which make up good practice should be attended to without the necessity for specific and detailed instruction. Such details include: grading poles to bring tops to approximately the same line; setting cross-arms square to tangent line, and bisecting the angle at breaks; setting brackets square to line and all with same rake; cutting in strains at the same relative points; installing spans so that eye-bolts and strands line up; setting chamfered nuts with flat side to bearing; seating insulator pins firmly to shoulder; seating washers square with bolt hole; screwing in lag screws at least the last half; finishing off all splices, fastenings and ends.

Catenary Construction

Endeavor to reduce the sag in overhead contact conductor by supplying several points of support in a given span resulted in the development of the catenary type of suspension. In its elementary form it consists in suspending the contact conductor means of clips or hangers which are placed a few feet apart and which are hung from one or more messenger wires which hang in nearly a catenary curve between the main supports of the overhead construction or between intermediate supports suspended therefrom. There are a great many varieties of this general form of suspension, varying from the simple catenary from which is suspended the trolley wire directly, to very elaborate suspension systems. The purpose of the catenary construction is to support the contact conductor at points close together while maintaining a great distance between points of support of the whole system, thus reducing changes in height of the contact conductor to a practical minimum without introducing excessive tension in the suspension system. The particular need for such a working conductor system is found in high speed work. At the present stage of development the advantages which might be derived from the use of the catenary type of suspension in city work, except in special cases such as over railroad crossings, are in general considered to be outweighed by the complications in its application and operation. There are three general types of primary suspension, namely: (1) bracket, (2) cross-span and (3) bridge. For extended discussions of many types of catenary construction the Transactions of the American Institute of Electrical Engineers should be consulted. The following is based upon an abstract of a paper by Mr. Charles Rufus Harte, Electric Railway Journal, 1914, which is a good summary of the more important catenary developments. Figs. 23 and 24 show typical examples of working conductor suspension in heavy electric railway work.

Length of Span. Messenger spans for catenary construction are usually 150 ft. with wood pole support, and 300 ft. on steel bridges; hanger spacing is generally 10 ft. to 15 ft. for pantograph operation, and twice these values for wheel operation.

General Details of Suspension. The earliest catenary consisted of a messenger from which the contact wire was suspended by a series of equidistant hangers. This worked well for short spans, but on long spans the great difference in length, and so in weight, of the mid and end hangers led to the development of compound catenary. The Siemens-Schukert type, one of the earliest forms, employs a main messenger, a secondary messenger suspended from the main messenger by hangers approximately 20 ft. apart, and a contact wire suspended from the secondary messenger by hangers approximately 10 ft. apart. The secondary messenger supports come at the quarter points between the main hangers or "droppers," which are of wire, about No. 8 gage equivalent, and are in two parts, linked eyes in the adjacent ends forming a flexible joint; these hangers attach rigidly to both main and secondary messenger. The secondary hangers attach rigidly to the contact wire, but loop over the secondary messenger so they are free to rise 2 or 3 in. This has proved very satisfactory in a number of Continental installations, and on the Midland Railway of England.

Multiple Catenary. Two main messengers have vertical sag and horizontal deflection toward each other. The hangers, spac

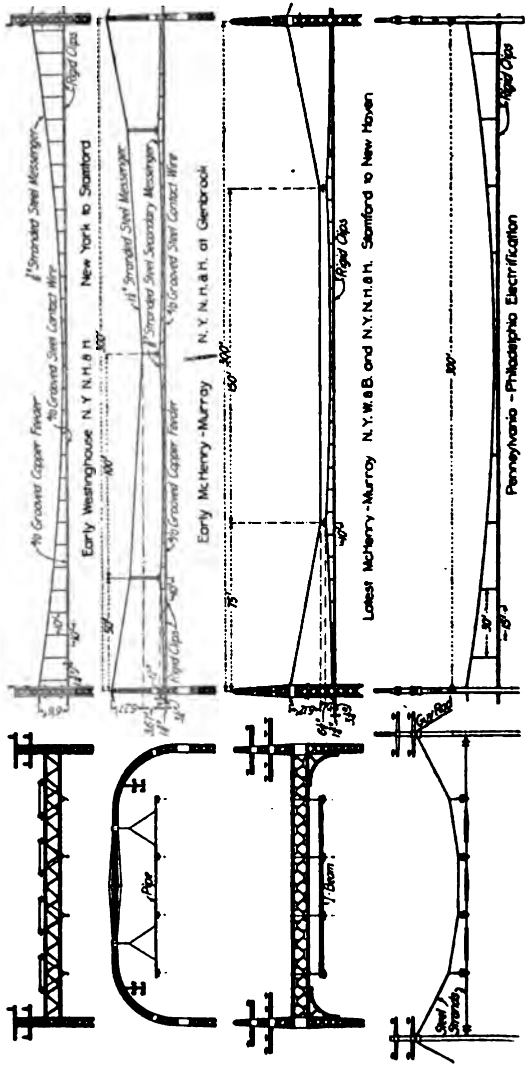
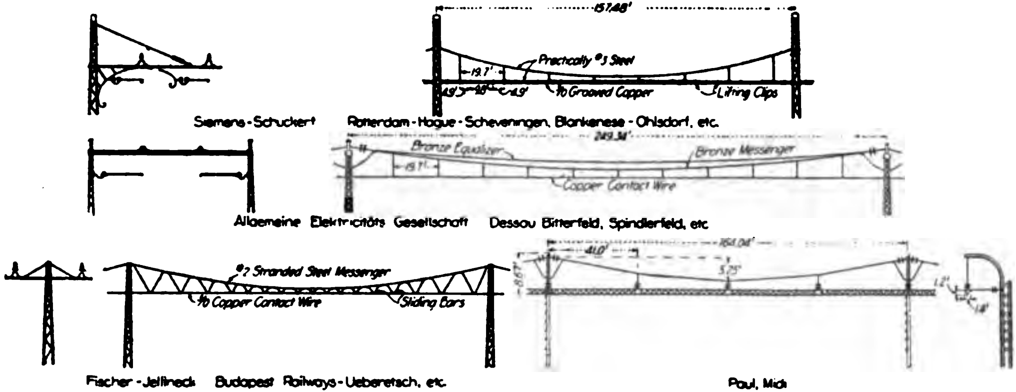

4/0 Grooved Copper Feeder
4/0 Grooved Steel Contact Wire
1/2" Stranded Steel Messenger
4/0 Grooved Steel Contact Wire
Rigid Clips
Early Westinghouse N.Y.N.H.& H. New York to Stamford
100'
300'
50'
9/16" Stranded Steel Messenger
1/2" Stranded Steel Secondary Messenger
4/0 Grooved Steel Contact Wire
4/0 Grooved Copper Feeder
Rigid Clips
Pipe
Early McHenry-Murray N.Y.N.H.& H. at Glenbrook
150'
300'
75'
Rigid Clips
I-Beam
Latest McHenry-Murray N.Y.W.& B. and N.Y.N.H.& H. Stamford to New Haven
300'
30'
15'
Rigid Clips
Guy Rod
Steel Strands
Pennsylvania - Philadelphia Electrification

FIG. 23.—Examples of typical catenary construction in America.



Siemens-Schuckert

Rotterdam-Hague-Scheveningen, Blankenese-Ohlsdorf, etc.

Allgemeine Elektricitäts Gesellschaft

Dessou Bitterfeld, Spindlerfeld, etc

Fischer-Jellinek

Budapest Railways-Ueberetsch, etc.

Paul, Midi

FIG. 24.—Examples of typical catenary construction in Europe.

10 ft. apart, are equilateral triangles of pipe, the two upper corners attaching to the messengers while the bottom one holds the contact wire; the entire system is at line potential, the supports at the bridges being insulators as well. As first installed on the New Haven road, the contact wire, No. 0000 grooved copper, was carried directly by the triangles. These points, however, were exceedingly rigid, while the midspan was comparatively soft, and when the speed of the train was such that the time interval between hanger points was the same as the vibration period of the collector, the latter chattered with increasing violence until changed conditions threw the pantograph "out of step."

Secondary Messenger. The trouble with the multiple catenary cited above was successfully obviated by the following improvement by Mr. E. H. McHenry: A steel contact wire of the same section as the copper is suspended from the latter by clips coming midway between the hangers, which keep the wires 1¾ in. apart, center to center. The clips are rigidly attached to both wires; it was feared that with the heavy shoe pressure a looped clip such as is used in the Siemens-Schukert form might permit the lower wire to turn sideways, in which case the shoe would foul the clips with disastrous results. The London-Brighton & South Coast Railway, to secure the same end, uses hangers of comparatively light wire, the small ones holding the wire by a loop, while the larger ones have jointed sides to give the desired flexibility. On this system the stresses are all low, the messenger having a sag of 6 ft. in vertical projection for a span of not quite 200 ft.

McHenry-Murray Suspension. The extensive experience with the pioneer and McHenry forms under heavy service, and careful study of the behavior of other types, resulted in the McHenry-Murrary catenary employed on the extension of the New Haven electrification. In this the main messengers, one for each track, have at the quarter points structural steel cross-bents which in turn carry insulators from which the secondary system is hung. This latter consists of the secondary messenger, carrying, through hangers 10 ft. apart, a pair of wires, upper of copper and lower of steel, held 1¾ in. center to center by clips which are midway between the secondary hangers. The main messengers have only to carry the mechanical load of the secondary system. The value of this grounded shield as a lightning protection has been strikingly shown in several electrical storms which caused trouble on the older forms, while the new construction in the same territory was unaffected.

Hard Catenary. The general tendency in catenary is toward a flexible line, but there are two recent marked exceptions. The Fischer-Jellinek form employed on the Budapest, Ueberetsch and other Austrian lines, has a triangular hanger which lies in the plane of the catenary and carries at the bottom angle an ear through which the trolley wire is free to slide. Continued and repeated use of this form apparently indicates successful results, but it is difficult to believe that even with the light bows employed there is not severe wear at these loose connections, particularly as the triangular hangers of this form, to insure that the clips remain parallel to the contact wire and do not bind on it, of necessity make very hard spots. This type is hard incidentally rather than by design, but the Paul catenary of the Midi Railway, France, is essentially hard, the messenger supporting a trussed member, which is an equilateral triangle, a contact rail being secured to the lower vertex while pull-offs and steady braces attach to the top which is horizontal. The trusses are a trifle more than 40 ft. long and are suspended by their ends, there being four to the span.

Catenary Hangers. A great variety of hangers has been tried, but very few of the forms have persisted, the majority either taking too much time to install or shaking loose in service, not a few doing both. That which seems to meet conditions best is a mechanical three-screw clip rigidly attached to a steel strap, the top of which is formed into a loop 3 in. or 4 in. long, permitting the contact wire to rise to that extent. The other types with cam, screw, toggle, wedge and other locking devices, many of them exceedingly ingenious, are for the most part of interest only as a matter of history. Early forms of strap hangers were hinged at the lower end, but this permitted the loop to tip over, and with each lift to crawl further out on the messenger until all the lift was taken up and the flexibility lost. To facilitate installation several ingenious ways of making the loop have been devised. In one the end is twisted back of the main stem, leaving a space of such shape that the hanger screws onto the messenger; another snaps into place, the spring of the shaft normally keeping the loop closed; while a third, also of the snap type, has the tail of the strap so bent up inside the loop that, once snapped on, the messenger cannot get into a position to wedge its way out.

Catenary Brackets. Brackets are of two classes: those made up of paired angles or channels, separated at one end, to go either side of the pole, to which they fasten by a through-bolt, or to clasp a casting lagged or bolted to the face of the pole; and those consisting of a single I or T seating in a suitable pole casting. Paired member brackets offer facilities for the attachment of supports, insulators and the like; single member forms offer much less opportunity for corrosion. Brackets which clasp the pole and are through-bolted to it restrict the length of line affected by a break to a few spans either side, but the brackets at the break are usually badly crippled if not completely wrecked; brackets less rigidly secured swing clear, and while dropping a much greater length of line are usually injured little if any. Abroad, brackets on special iron poles are used for spans up to 300 ft., and frequently for double-track work, either with center-pole construction or carrying both trolley wires on the one long arm. In American practice two-track brackets are not so frequently used, spans or bridges being employed instead; the latter are also extensively employed on long span foreign lines.

Cross Span Catenary. Cross span support has the marked advantage of causing minimum interference with the view of the motorman, but the sag must be great or the stresses will be very high. It has been used in some of the early light catenary construction and the New York, New Haven & Hartford Railroad has made extensive use of this construction for yard work, and to a small extent for the main line, employing heavy lattice poles to sustain it. The span wire attaches to the main catenary messenger, while a steady strand attached at or near the contact wire prevents overturning under pantograph pressure. In some instances the span has contained a section of structural steel carrying insulators to which the messengers attach. The New Haven type has long wooden strains in the steady strand, very materially stiffening it.

Bridge Catenary. For heavy work most engineers have preferred a stiff cross member to the high or heavy poles required for cross span support. Bridges have a wide range of design, from the light paired angle irons bolted to wooden poles, one on each side of the track, as on the Midland Railway, England, and certain Continental lines, and the light but rigid entirely structural material frames of the Archbold-Brady type, to the very substantial structures of the early New Haven work. The importance of the traffic involved in the latter case and the lack of data as to behavior in such service justified the use of a conservative design in the pioneer installation.

Alinement of Contact Wire. Abroad the line is zigzagged from side to side, usually about 1 ft. each way, to distribute the wear over the top of the shoe. In America the line is almost always centered, probably for esthetic reasons, although it is found that the natural side sway of the pantograph is ample to give all necessary side travel. Even with center location it is essential that track and overhead departments maintain close co-operation lest a change in super-elevation without a corresponding line shift result in the shoe being thrown entirely clear of the contact wire because of unavoidable side play.

Turnout Diverters. At turnouts the diverging wire is lifted above the level of that of the main line, but for pantograph operation early American catenaries used a gridiron of wires to fill in the space between wires to a point where the end of the shoe could by no chance go over the branch wire. Later designs follow the foreign practice of merely raising the branch wire, which, however, is rigidly held to that elevation throughout the fouling space by special double hangers.

Catenary Curve Dressing. Curve dressing is complicated, particularly on flexible simple catenary. To prevent tipping there must be two attachments: if made to the hanger rod the friction on the messenger absorbs much of the flexibility; if one attachment is made to the hanger rod or contact wire and the other to the messenger the pull-together effect of paired strands is equally undesirable. The best solution is the use of a spreader which keeps the two parts parallel for at least 6 ft. or 8 ft. from the catenary, beyond which they come together in a common pull-off. On rigid hanger lines this is unnecessary and the strands are attached to the messenger and to the bottom of the hanger rod or to an attachment to the contact wire which, for pantograph work, is sufficiently offset to prevent fouling. Sharp curves with several pulls per span employ either a bridle between supports to which the pulls are run radially, or else the pulls are run to the supports in fans; light curves either use the bridle or fan method, or on heavy construction use a special pull-off pole. On light work flat curves offer so little side pull that the weight of the strands and insulator causes heavy sag; in one instance this was partly obviated by using a light single strand, which a short distance from the catenary was divided into two groups of three wires each, the seventh being served on to prevent further unlaying. One group of three wires was then taken to the messenger, the other to the trolley, while the insulator was cut in at the bridle. Foreign lines and a few American employ the rigid steady brace attached to the main support, and rarely to a pole specially set for it. The elimination of special pull-off poles is secured, and the disadvantage of the line loading by the steady brace is obviated by extending the bracket to form a hook to which a pull-off strand is attached. In case the pole is on the outside of the curve the attachment is made directly to it. The use of cross-bents on the Harlem Branch electrification of the New Haven permitted the use of a bridle tied to these bents, pulling them partly to the desired offset from the chord of the messenger, a further shift of the insulators on the cross-bents bringing the contact wire over the track center. The most admirable device, however, is the Murray curve hanger, the head of which firmly grips the messenger, holding the shank at an angle of approximately 45 deg. from the vertical, while the lower end is a duplex clip, which is vertical. The lengths are such that the clips are true to line, making the chords but 10 ft., while the inclined shank permits the contact wire to yield to the pressure of the shoe against the torsion of the messenger and the pull of the contact wire. In connection with shortened support spacing to keep the hanger lengths within reasonable limits, this scheme, employed on the recent New Haven work and now used on the Pennsylvania, gives an almost perfectly true alinement.

Temperature Changes. Changes in temperature tend to cause corresponding length changes in the various members of catenary construction, but the actual result is largely affected by the character of the construction. The messenger, contracting or expanding, tends to lower or rise, the movement being a maximum at mid-span, and zero at supports; the contact wire tends to do likewise, but at a different rate because of its different sag. The hangers tie the two together and compel equal movement, giving to the contact wire in cold weather an inverted sag, so to speak, and in hot weather slack wire between the hangers. On the Syracuse, Lake Shore & Northern Railway, the contact wire, which was erected in winter, was given a very high initial tension and an inverted sag of 1 ft. to the standard 300-ft. span, so that the heavy summer traffic should have a fairly tight straight line. With this one exception, which, it is said, did not entirely meet expectations in this respect, American engineers have considered compensation devices not worth the complication, a belief well justified by the behaviot of the lines which are in service without such devices.

Sag and Horizontal Pull in Span

Single-track Line.—The following table shows the sag resulting in spans of various lengths when subjected to the tensions given, a standard span weight of 50 lb. being assumed. This is a convenient standard weight for a 5/16-in. steel strand span which supports a length of 100 ft. of 00 trolley with ear and insulator.

SAG IN SPAN WIRE—SINGLE-TRACK LINE

Maximum Sag in Inches (c) for Weight (W) of 50 Lb.

Pull on span (P) in pounds	Length of span (S) in feet										
	30	35	40	45	50	55	60	65	70	75	80
500	9.0	10.5	12.0	13.5	15.0	16.5	18.0	19.5	21.0	22.5	24.0
600	7.5	8.8	10.0	11.3	12.5	13.8	15.0	16.3	17.5	18.8	20.0
700	6.4	7.5	8.6	9.6	10.7	11.8	12.9	13.9	15.0	16.1	17.1
800	5.6	6.6	7.5	8.4	9.4	10.3	11.3	12.2	13.1	14.1	15.0
900	5.0	5.8	6.7	7.5	8.3	9.2	10.0	10.8	11.7	12.5	13.3
1000	4.5	5.3	6.0	6.8	7.5	8.3	9.0	9.8	10.5	11.3	12.0
1100	4.1	4.8	5.5	6.1	6.8	7.5	8.2	8.9	9.5	10.2	10.9
1200	3.8	4.4	5.0	5.7	6.3	6.9	7.5	8.2	8.8	9.4	10.0
1300	3.5	4.0	4.6	5.2	5.8	6.3	6.9	7.5	8.1	8.7	9.2
1400	3.2	3.8	4.3	4.8	5.4	5.9	6.4	7.0	7.5	8.1	8.6
1500	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
1600	2.8	3.3	3.8	4.2	4.7	5.2	5.7	6.1	6.6	7.0	7.5
1700	2.6	3.1	3.5	4.0	4.4	4.9	5.3	5.7	6.2	6.6	7.1
1800	2.5	2.9	3.3	3.7	4.2	4.6	5.0	5.4	5.8	6.2	6.7
1900	2.4	2.8	3.2	3.6	4.0	4.3	4.7	5.1	5.5	5.9	6.3
2000	2.3	2.6	3.0	3.4	3.8	4.1	4.5	4.9	5.3	5.6	6.0
2100	2.1	2.5	2.9	3.2	3.6	3.9	4.3	4.7	5.0	5.4	5.7
2200	2.2	2.4	2.7	3.1	3.4	3.8	4.1	4.4	4.8	5.1	5.5
2300	2.0	2.3	2.6	2.9	3.3	3.6	3.9	4.2	4.6	4.9	5.2
2400	1.9	2.2	2.5	2.8	3.1	3.4	3.8	4.1	4.4	4.7	5.0
2500	1.8	2.1	2.4	2.7	3.0	3.3	3.6	3.9	4.2	4.5	4.8

Sags are computed from the formula $c_1 = \frac{3WS}{P}$ in which $W = 50$ for single-track lines.

Double-track Line. The following table shows the sag resulting in spans of various lengths when subjected to the tensions given, a standard span weight of 100 lb. being assumed. This is a convenient standard weight for a ⅜-in. steel strand span which supports a length of 100 ft. of two 00 trolley wires, insulators and ears.

SAG IN SPAN WIRES—DOUBLE-TRACK LINE

Maximum Sag in Inches (*c*) for Weight (*W*) of 100 Lb.

Horizontal pull on span (*P*) in pounds	Length of span (*S*) feet										
	30	35	40	45	50	55	60	65	70	75	80
50	120.0	150.0	180.0	210.0	240.0	270.0	300.0	330.0	360.0	390.0	420.0
100	60.0	75.0	90.0	105.0	120.0	135.0	150.0	165.0	180.0	195.0	210.0
150	40.0	50.0	60.0	70.0	80.0	90.0	100.0	110.0	120.0	130.0	140.0
200	30.0	37.5	45.0	52.5	60.0	67.5	75.0	82.5	90.0	97.5	105.0
250	24.0	30.0	36.0	42.0	48.0	54.0	60.0	66.0	72.0	78.0	84.0
300	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0	60.0	65.0	70.0
400	15.0	18.8	22.5	26.3	30.0	33.8	37.5	41.3	45.0	48.8	52.5
500	12.0	15.0	18.0	21.0	24.0	27.0	30.0	33.0	36.0	39.0	42.0
600	10.0	12.5	15.0	17.5	20.0	22.5	25.0	27.5	30.0	32.5	35.0
700	8.6	10.7	12.9	15.0	17.1	19.3	21.4	23.6	25.7	27.9	30.0
800	7.5	9.4	11.3	13.1	15.0	16.9	18.8	20.6	22.5	24.4	26.3
900	6.7	8.3	10.0	11.7	13.3	15.0	16.7	18.3	20.0	21.7	23.3
1000	6.0	7.5	9.0	10.5	12.0	13.5	15.0	16.5	18.0	19.5	21.0
1100	5.5	6.8	8.2	9.6	10.9	12.3	13.6	15.0	16.3	17.7	19.1
1200	5.0	6.3	7.5	8.8	10.0	11.3	12.5	13.8	15.0	16.3	17.5
1300	4.6	5.8	6.9	8.1	9.3	10.4	11.5	12.7	13.8	15.0	16.2
1400	4.3	5.4	6.4	7.4	8.6	9.6	10.7	11.8	12.9	13.9	15.0
1500	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0
1600	3.8	4.7	5.6	6.6	7.5	8.4	9.4	10.3	11.3	12.2	13.1
1700	3.5	4.4	5.3	6.2	7.1	7.9	8.8	9.7	10.6	11.5	12.4
1800	3.3	4.2	5.0	5.8	6.7	7.5	8.3	9.2	10.0	10.8	11.7
1900	3.2	4.0	4.7	5.5	6.3	7.1	7.9	8.7	9.5	10.3	11.1
2000	3.0	3.8	4.5	5.3	6.0	6.8	7.5	8.3	9.0	9.8	10.5
2100	2.9	3.6	4.3	5.0	5.7	6.4	7.1	7.9	8.6	9.3	10.0
2200	2.7	3.4	4.1	4.8	5.5	6.1	6.8	7.5	8.2	8.9	9.5
2300	2.6	3.3	3.9	4.6	5.2	5.9	6.5	7.2	7.8	8.5	9.1
2400	2.5	3.1	3.8	4.4	5.0	5.6	6.3	6.9	7.5	8.1	8.8
2500	2.4	3.0	3.6	4.2	4.8	5.4	6.0	6.6	7.2	7.8	8.4

Sags computed from the formula $c = \frac{3W(S-a)}{P}$ in which $W = 100$ and $a = 10$ for double track.

The values in the above table are plotted in Figs. 25 and 26. For other sizes of wire strand or trolley the weight of the span will be different. The table on page 621 shows the "loading factor" or ratio of weight of various spans to the weight of the assumed standard span of 100 lb. The sag given in the above table, when multiplied by the proper "loading factor," will give the sag in any desired span.

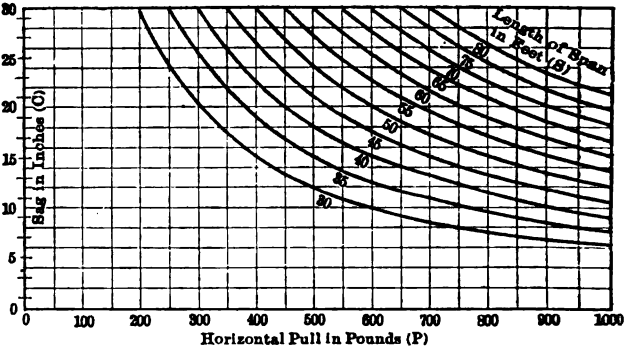


FIG. 25.—Sag and horizontal pull of double trolley span wires. (See also Fig. 26.)

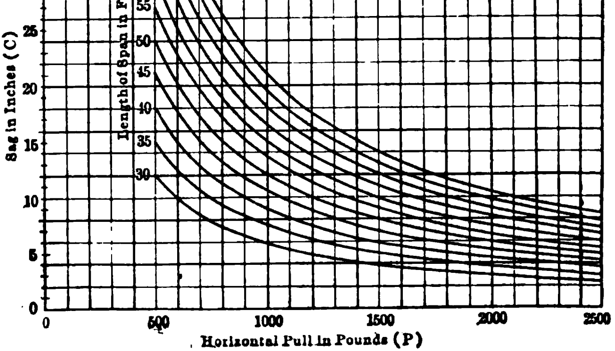


FIG. 26.—Sag and horizontal pull of double-track span wires. (See also Fig. 25.)

LOADING FACTORS FOR CALCULATING SAGS IN DOUBLE TROLLEY SPAN WIRES

These factors are to be used as multipliers of the sags for standard loading given in the Table on page 619 to determine the sag for any other loading

Span wire	¼-in.				5/16-in.				⅜-in.				7/16-in.			
Safe working stress in pounds	1150				1900				2500				3250			
Trolley wire	0	00	000	0000	0	00	000	0000	0	00	000	0000	0	00	000	0000
30 ft. length of span	0.85	1.01	1.22	1.49	0.87	1.04	1.25	1.51	0.90	1.06	1.25	1.54	0.93	1.10	1.31	1.60
35 ft.	0.85	1.02	1.23	1.49	0.88	1.05	1.26	1.52	0.91	1.08	1.27	1.55	0.96	1.12	1.33	1.62
40 ft.	0.86	1.03	1.24	1.50	0.89	1.06	1.27	1.53	0.93	1.09	1.28	1.57	0.98	1.14	1.35	1.64
45 ft.	0.87	1.03	1.24	1.51	0.90	1.07	1.27	1.55	0.94	1.11	1.30	1.58	1.00	1.16	1.37	1.66
50 ft.	0.87	1.04	1.25	1.51	0.91	1.08	1.28	1.56	0.96	1.12	1.31	1.60	1.02	1.18	1.39	1.68
55 ft.	0.88	1.04	1.25	1.52	0.93	1.09	1.29	1.57	0.97	1.14	1.33	1.61	1.04	1.20	1.41	1.70
60 ft.	0.89	1.05	1.26	1.52	0.94	1.10	1.30	1.58	0.99	1.15	1.34	1.63	1.06	1.23	1.43	1.72
65 ft.	0.89	1.06	1.27	1.53	0.95	1.11	1.31	1.59	1.00	1.17	1.36	1.64	1.08	1.25	1.46	1.74
70 ft.	0.90	1.06	1.27	1.54	0.96	1.12	1.32	1.60	1.02	1.18	1.37	1.66	1.10	1.27	1.48	1.76
75 ft.	0.90	1.07	1.28	1.54	0.97	1.13	1.33	1.61	1.03	1.20	1.39	1.67	1.12	1.29	1.50	1.78
80 ft.	0.91	1.08	1.29	1.55	0.98	1.14	1.33	1.62	1.06	1.21	1.40	1.69	1.14	1.31	1.52	1.80

In determining the safe working stress, a factor of safety of 2 was used.

The factors multiplied by 100 give the approximate total weight of the span and two trolley wires.

The following material makes up the span: 4 strain insulators; 2 straight line hangers; 2 trolley ears; seven-strand galvanized iron wire.

WEIGHTS OF MATERIAL

Straight line hangers	3.25 lb. each	0000 trolley wire per ft.	0.6398 lb.
Ears	0.8 lb. each	000 trolley wire per ft.	0.5073 lb.
¼-in. galvanized wire, 7-strand	0.125 lb. per ft.	00 trolley wire per ft.	0.4024 lb.
5/16-in. galvanized wire, 7-strand	0.21 lb. per ft.	0 trolley wire per ft.	0.3194 lb.
⅜-in. galvanized wire, 7-strand	0.295 lb. per ft.	Strain insulators	2.25 lb. each.
7/16-in. galvanized wire, 7-strand	0.415 lb. per ft.		

High Conductivity Trolley Wire, Round and Grooved

(A.E.R.E.A. Standard)

Material. The material of which high conductivity trolley wire is made should be electrolytic or low resistance lake copper wire bars of quality specified by standard specifications for electrolytic copper wire bars, cakes, slabs, billets, ingots, and ingot bars, or lake copper wire bars, cakes, slabs, billets, ingots, and ingot bars, adopted by the American Society for Testing Materials, August 25, 1913. Necessary brazes in trolley wire should be made in accordance with the best commerical practice, and tests upon a section of wire containing a braze should show at least 95 per cent. of the tensile strength of the unbrazed wire. Elongation tests should not be made on test sections including brazes. The wire should be of uniform size, shape, and quality throughout, and should be free from all scale, flaws, splits and scratches not consistent with the best commercial practice.

Round Trolley Wire

(A.E.R.E.A. Standard)

Dimensions. Dimensions of round trolley wire should be expressed as the diameter of the wire in decimal fractions of an inch, using not more than three places of decimals; *i.e.*, in even mils. Wire should be accurate in diameter. Variations of 1 per cent. over or under nominal diameter are permissible.

Tensile Strength and Elongation. Round trolley wire should be so drawn that its tensile strength will not be less than the minimum values, nor more than the maximum values, and its elongation not less than the minimum values, given in the following table:

Diameter, in.	Area, cir. mils	Tensile strength, lb. per sq. in.		Elongation in 10 in. (per cent.)
		Minimum	Maximum	
0.460	211,600	49,000	53,000	3.75
0.410	168,100	50,000	54,000	3.25
0.365	133,200	51,600	56,000	2.80

The elongation should be determined as the permanent increase in length due to the breaking of the wire in tension measured between bench marks placed upon the wire originally 10 in. apart. The fracture should be between the bench marks and not closer than 1 in. to either bench mark.

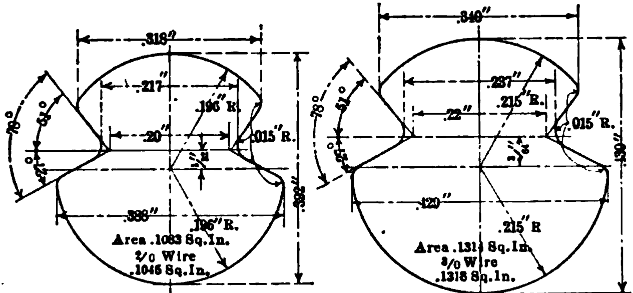
Inspection for Defects. For the purpose of determining and developing defects which may be prejudicial to the life of trolley wire, owing to its peculiar service, as compared to that of copper wire for other purposes, the following twisting tests should be made. Three twist tests should be made upon samples 10 in. long between the holders of the machine. All three samples should be twisted to destruction and should not reveal under test any seams, pits, slivers, or surface imperfections not consistent with the best commercial practice. At the time of fracture the wire should be twisting with reasonable uniformity. All samples should withstand the following minimum number of turns without breaking.

Diameter, in.	Area, cir. mils	Twist in 10 in.
0.460	211,600	8
0.410	168,100	9
0.365	133,200	10

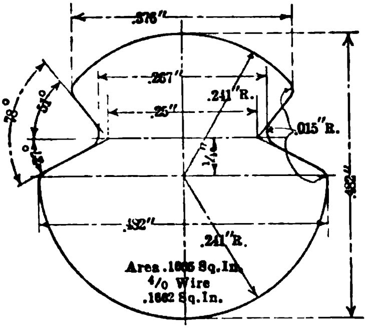
The twisting machine should be so constructed that there is a linear motion of the tailstock with respect to the head. The twist shall be applied not faster than ten turns per minute.

Resistivity. Electric resistivity should be determined upon fair samples by resistance measurements at a temperature of 20 deg. C. (68 deg. F.). The wire should not exceed in resistivity 900.77 lb. per mile ohm.

Density. For the purpose of calculating weights, cross-sections, etc., the specific gravity of copper should be taken as 8.89 at 20 deg. C.



2/0 Wire 3/0 Wire



4/0 Wire

FIG. 27.—American standard grooved trolley wire sections.

Grooved Trolley Wire

(A.E.R.E.A. Standard)

Standard sections are shown by Fig. 27. These are known as the "American Standard Grooved Trolley Wire Sections," and have been adopted as standard by the Am. El. Ry. Eng. Assn., the Am. Soc. for Testing Materials, and many wire manufacturers.

Dimensions. Dimensions of grooved trolley wire should be expressed as the area of cross-section in circular mils, the standard sizes being as follows:

211,600 cir. mils weighing 3,386 lb. per mile.
168,100 cir. mils weighing 2,660 lb. per mile.
133,200 cir. mils weighing 2,132 lb. per mile.

Grooved trolley wire may vary 4 per cent over and under in weight per unit length from standard as determined from the nominal cross-section.

Physical Tests. Physical tests on grooved trolley wire should be made in the same manner as those upon the round wire (see page 622). The tensile strength of grooved wire should be at least 95 per cent. of that required for round wire of the same sectional area; the elongation should be the same as that required for round wire of the same sectional area. The twist test should be omitted.

Resistivity. The requirements for resistivity are the same as those for round wire of the same sectional area (see page 623).

Cap and Cone Insulator Dimensions

(A.E.R.E.A. Standard)

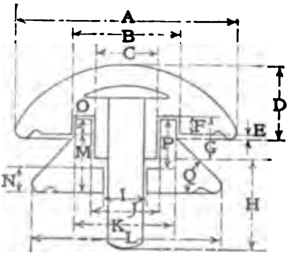


FIG. 28.

Key letter		Dimension		Allowable variation
A.		$3\frac{15}{32}$	in.	Not over $\frac{1}{8}$ in.
B.		1^{21}	in.	Not over $\frac{1}{64}$ in.
C.		1	in.	None over.
D.	Min.	$1\frac{5}{64}$	in.	
	Max.	$1\frac{23}{64}$	in.	
E.		$\frac{1}{16}$	in.	Not over $\frac{1}{8}$ in.
F.		$\frac{1}{4}$	in.	None less.
G.		$\frac{3}{8}$	in.	None over.
H.		$1\frac{1}{4}$	in.	Not over $\frac{1}{64}$ in.
I.		$\frac{21}{32}$	in.	Not over $\frac{1}{8}$ in.
J.		$1\frac{1}{32}$	in.	None less.
K.		$1\frac{5}{8}$	in.	None over.
L.	Min.	$2\frac{7}{8}$	in.	
	Max.	3	in.	
M.		1	in.	Not over $\frac{1}{64}$ in.
N.		$\frac{3}{8}$	in.	None over.
O.		$\frac{1}{4}$	in.	None over.
P.		$\frac{7}{8}$	in.	None.
Q.		50°		None.

Selection of Poles

The selection of the pole for trolley line construction is dependent upon the type of line which is to be supported, and involves three elements, namely, height of pole, width of street for span construction, and sag desired in span. The allowable sag having been decided upon, the next step is to find the horizontal pull for the span wire. This is found as shown on pages 618 to 621, and the pole of the desired length must then be selected to withstand the pull thus determined. If the pole selected has a deflection of say 3 in. for the required pull, then the pole must be given a 3 in. rake if it is desired to pull it up vertically when the span is completed.

Steel Poles

Deflection.

$$x = \frac{Pl^3}{3EI}$$

in which x = deflection in inches, 18 in. from top of pole
P = horizontal pull, 18 in. from top of pole
l = length of pole from point of application of P to ground line (6 ft. from base end), in inches
E = modulus of elasticity of steel (26,000,000)
I = moment of inertia of base section.

Deflections from various loadings together with descriptions of poles are given in the following tables. The variations of lengths of the sections of a pole within commercial limits have but little effect upon its strength, stiffness, or weight. The section lengths given conform closely to those usually employed. In general a number of poles will satisfy the requirements, and choice must be made from those of the proper length. Usually the lightest weight pole would be selected unless the deflection was considered too great, in which case the choice would be determined finally by the deflection.

Steel Pipe used in making Poles. All steel pipe used in making up poles should be good quality of mild steel of uniform thickness, free from bad welds, cold shuts, outside slivers, cracks, flaws, open seams, rivets or other imperfections which would affect the strength, life or appearance of the pole. The table on page 630 gives data on steel pipe which was used in making up the tables on pages 626 to 629.

Joints in Steel Poles. The joints should be 18 in. in length and should be made hot without reducing the diameter of the smaller pipe more than ⅛ in., and without any reduction in the thickness of either pipe. The completed joint should caliper the same outside diameter for its entire length, should be free from cracks or flaws, and should be water tight. Any pole when dropped three times from a height of 6 ft. upon a solid wooden block on a rigid base should not show any telescoping at the joints.

Ground Sleeve. A ground sleeve, if required, should be made of standard weight pipe 3 ft. in length; it should be shrunk on the butt section with the center of the sleeve 6 ft. from the base of the pole.

Wood Poles

Classification According to Purpose, A.E.R.E.A. Standard. To determine the character of poles to be used in trolley line construction, they may be divided into three classes, A, B, C.

Class A. For span construction on streets or rights of way where a 35 ft. span is required, or for heavy feeder lines carrying from one to six cross-arms.

TUBULAR STEEL POLES—DEFLECTIONS AND LOADS

Description of poles									Pole set 6 ft. 0 in. in ground—load applied and deflection measured 18 in. from free end, probable deflections when held and loaded as stated													Greatest safe load in lb.	Length in ft.
Length in ft.	Size and kind of pipe				Weight of pole	Section lengths—ft.			Top line gives loads in lb. applied 18 in. from free end of pole														
	Butt		Middle	Top																			
	Std.	Ex. Hvy.	Std.	Std.		Butt	Middle	Top	500	600	800	1000	1200	1400	1600	1800	2100	2400	2700	3000	3300		
28	5	....	4	3	384	18	7	6	6.27	....	....	....	....	....	....	....	....	....	....	....	....	524	28
28	....	5	4	3	495	18	7	6	4.63	....	....	....	....	....	....	....	....	....	....	....	....	604	28
28	6	....	5	4	509	18	7	6	3.29	4.07	....	....	....	....	....	....	....	....	....	....	....	690	28
28	....	6	5	4	681	18	7	6	2.54	2.94	3.92	4.90	....	....	....	....	....	....	....	....	....	956	28
28	7	....	6	5	644	18	7	6	2.05	2.46	3.28	4.10	....	....	....	....	....	....	....	....	....	1033	28
28	....	7	6	5	905	18	7	6	1.34	1.60	2.14	2.67	3.20	3.74	....	....	....	....	....	....	....	1460	28
28	8	....	7	6	793	18	7	6	1.32	1.58	2.10	2.63	3.16	3.68	....	....	....	....	....	....	....	1367	28
28	....	8	7	6	1060	18	7	6	0.90	1.08	1.44	1.80	2.16	2.52	2.88	3.44	....	....	....	....	....	2000	28
28	9	....	8	7	951	18	7	6	0.89	1.06	1.42	1.77	2.12	2.48	2.83	3.19	....	....	....	....	....	1828	28
28	....	9	8	7	1218	18	7	6	0.64	0.77	1.02	1.28	1.53	1.79	2.04	2.19	2.56	2.93	....	....	....	2530	28
28	10	....	9	8	1137	18	7	6	0.59	0.71	0.95	1.19	1.43	1.67	1.90	2.14	2.50	2.86	....	....	....	2517	28
28	....	10	9	8	1394	18	7	6	0.45	0.54	0.72	0.90	1.08	1.26	1.44	1.62	1.89	2.16	2.43	2.70	2.97	3300	28
29	5	....	4	3	392	18	7	7	7.24	....	....	....	....	....	....	....	....	....	....	....	....	500	29
29	....	5	4	3	503	18	7	7	5.33	....	....	....	....	....	....	....	....	....	....	....	....	576	29
29	6	....	5	4	519	18	7	7	3.91	4.69	....	....	....	....	....	....	....	....	....	....	....	660	29
29	....	6	5	4	692	18	7	7	2.83	3.39	4.52	....	....	....	....	....	....	....	....	....	....	912	29
29	7	....	6	5	659	18	7	7	2.36	2.84	3.78	4.73	....	....	....	....	....	....	....	....	....	985	29
29	....	7	6	5	920	18	7	7	1.54	1.85	2.64	3.08	3.70	4.31	....	....	....	....	....	....	....	1390	29
29	8	....	7	6	812	18	7	7	1.52	1.82	2.42	3.03	3.64	4.24	....	....	....	....	....	....	....	1303	29
29	....	8	7	6	1079	18	7	7	1.04	1.25	1.66	2.08	2.50	2.91	3.33	....	....	....	....	....	....	1900	29
29	9	....	8	7	975	18	7	7	1.02	1.22	1.62	2.03	2.44	2.84	3.25	....	....	....	....	....	....	1742	29
29	....	9	8	7	1242	18	7	7	0.74	0.88	1.18	1.47	1.76	2.06	2.35	2.65	3.09	3.53	....	....	....	2410	29
29	10	....	9	8	1166	18	7	7	0.69	0.82	1.10	1.37	1.64	1.92	2.19	2.47	2.88	3.29	....	....	....	2400	29
29	....	10	9	8	1422	18	7	7	0.52	0.62	0.83	1.04	1.25	1.46	1.66	1.87	2.18	2.50	2.81	3.12	....	3088	29

TUBULAR STEEL POLES—DEFLECTIONS AND LOADS.—*Continued*

Description of poles									Pole set 6 ft. 0 in. in ground—load applied and deflection measured 18 in. from free end, probable deflections when held and loaded as stated														
Length in ft.	Size and kind of pipe				Weight of pole	Section lengths—ft.			Top line gives loads in lb. applied 18 in. from free end of pole													Greatest safe load in lb.	Length in ft.
	Butt		Middle	Top																			
	Std.	Ex. Hvy.	Std.	Std.		Butt	Middle	Top	500	600	800	1000	1200	1400	1600	1800	2100	2400	2700	3000	3300		
30	5	....	4	3	406	18	9	6	....	....	....	....	....	....	....	....	....	....	....	....	....	480	30
30	....	5	4	3	517	18	9	6	6.10	....	....	....	....	....	....	....	....	....	....	....	....	550	30
30	6	....	5	4	538	18	9	6	4.49	5.38	....	....	....	....	....	....	....	....	....	....	....	629	30
30	....	6	5	4	711	18	9	6	3.24	3.89	5.18	....	....	....	....	....	....	....	....	....	....	870	30
30	7	....	6	5	682	18	9	6	2.71	3.25	4.34	5.42	....	....	....	....	....	....	....	....	....	941	30
30	....	7	6	5	943	18	9	6	1.77	2.12	2.82	3.53	4.24	....	....	....	....	....	....	....	....	1330	30
30	8	....	7	6	840	18	9	6	1.74	1.99	2.78	3.48	3.97	....	....	....	....	....	....	....	....	1245	30
30	....	8	7	6	1107	18	9	6	1.20	1.43	1.91	2.39	2.87	3.35	3.82	....	....	....	....	....	....	1664	30
30	9	....	8	7	1009	18	9	6	1.17	1.40	1.86	2.33	2.80	3.62	3.73	....	....	....	....	....	....	1665	30
30	....	9	8	7	1275	18	9	6	0.94	1.02	1.35	1.69	2.03	2.37	2.70	3.04	3.55	....	....	....	....	2303	30
30	10	....	9	8	1205	18	9	6	0.78	0.94	1.25	1.56	1.87	2.18	2.50	2.81	3.28	3.74	....	....	....	2293	30
30	....	10	9	8	1462	18	9	6	0.60	0.72	0.96	1.20	1.44	1.68	1.92	2.16	2.52	2.88	3.24	3.60	....	3000	30
31	5	....	4	3	413	18	9	7	....	....	....	....	....	....	....	....	....	....	....	....	....	458	31
31	....	5	4	3	524	18	9	7	7.17	....	....	....	....	....	....	....	....	....	....	....	....	527	31
31	6	....	5	4	549	18	9	7	6.79	6.32	....	....	....	....	....	....	....	....	....	....	....	602	31
31	....	6	5	4	721	18	9	7	3.81	4.57	6.09	....	....	....	....	....	....	....	....	....	....	834	31
31	7	....	6	5	697	18	9	7	3.19	3.82	5.10	....	....	....	....	....	....	....	....	....	....	900	31
31	....	7	6	5	958	18	9	7	2.08	2.90	3.32	4.15	4.98	5.61	....	....	....	....	....	....	....	1272	31
31	8	....	7	6	859	18	9	7	2.05	2.46	3.28	4.10	4.92	5.74	....	....	....	....	....	....	....	1192	31
31	....	8	7	6	1126	18	9	7	1.40	1.68	2.24	2.80	3.36	3.92	4.48	5.04	....	....	....	....	....	1742	31
31	9	....	8	7	1032	18	9	7	1.37	1.64	2.19	2.74	3.29	3.84	4.38	4.93	....	....	....	....	....	1600	31
31	....	9	8	7	1299	18	9	7	0.98	1.19	1.58	1.98	2.38	2.87	3.17	3.56	4.31	....	....	....	....	2205	31
31	10	....	9	8	1234	18	9	7	1.29	1.10	1.47	1.84	2.21	2.58	2.94	3.31	3.86	....	....	....	....	2200	31
31	....	10	9	8	1490	18	9	7	0.70	0.84	1.12	1.40	1.68	1.96	2.24	2.52	2.94	3.36	3.78	....	....	2870	31

TUBULAR STEEL POLES—DEFLECTIONS AND LOADS.—*Continued*

Description of poles									Pole set 6 ft. 0 in. in ground—load applied and deflection measured 18 in. from free end, probable deflections when held and loaded as stated													Greatest safe load in lb.	Length in ft.
Length in ft.	Size and kind of pipe				Weight of pole	Section lengths—ft.			Top line gives loads in lb. applied 18 in. from free end of pole														
	Butt		Middle	Top		Butt	Middle	Top	500	600	800	100	1200	1400	1600	1800	2100	2400	2700	3000	3300		
	Std.	Ex. Hvy.	Std.	Std.																			
32	5	....	4	3	429	19	9	7	....	....	....	....	....	....	....	....	....	....	....	....	....	440	32
32	....	5	4	3	545	19	9	7	7.90	....	....	....	....	....	....	....	....	....	....	....	....	505	32
32	6	....	5	4	566	19	9	7	5.79	....	....	....	....	....	....	....	....	....	....	....	....	578	32
32	....	6	5	4	750	19	9	7	2.50	5.00	6.67	....	....	....	....	....	....	....	....	....	....	800	32
32	7	....	6	5	720	19	9	7	3.50	4.20	5.60	....	....	....	....	....	....	....	....	....	....	864	32
32	....	7	6	5	996	19	9	7	2.28	2.74	3.65	4.56	5.47	....	....	....	....	....	....	....	....	1220	32
32	8	....	7	6	887	19	9	7	2.25	2.69	3.59	4.49	5.39	....	....	....	....	....	....	....	....	1147	32
32	....	8	7	6	1169	19	9	7	1.54	1.85	2.46	3.08	3.70	4.31	4.93	....	....	....	....	....	....	1668	32
32	9	....	8	7	1066	19	9	7	1.51	1.81	2.41	3.01	3.61	4.22	4.82	....	....	....	....	....	....	1530	32
32	....	9	8	7	1348	19	9	7	1.09	1.31	1.74	2.18	2.62	3.05	3.49	3.92	4.58	....	....	....	....	2115	32
32	10	....	9	8	1274	19	9	7	0.97	1.16	1.55	1.93	2.32	2.71	3.09	3.48	4.06	....	....	....	....	2072	32
32	....	10	9	8	1545	19	9	7	0.53	0.64	0.85	1.07	1.28	1.49	1.70	1.92	2.24	2.56	2.88	....	....	2750	32
33	5	....	4	3	440	19	10	7	....	....	....	....	....	....	....	....	....	....	....	....	....	442	33
33	....	5	4	3	556	19	10	7	....	....	....	....	....	....	....	....	....	....	....	....	....	486	33
33	6	....	5	4	582	19	10	7	6.54	....	....	....	....	....	....	....	....	....	....	....	....	555	33
33	....	6	5	4	765	19	10	7	4.72	....	....	....	....	....	....	....	....	....	....	....	....	768	33
33	7	....	6	5	739	19	10	7	3.95	4.74	6.31	....	....	....	....	....	....	....	....	....	....	830	33
33	....	7	6	5	1015	19	10	7	2.57	3.08	4.11	5.14	6.17	....	....	....	....	....	....	....	....	1172	33
33	8	....	7	6	911	19	10	7	2.53	3.04	4.05	5.06	6.07	....	....	....	....	....	....	....	....	1000	33
33	....	8	7	6	1193	19	10	7	1.74	2.09	2.78	3.48	4.18	4.87	5.57	....	....	....	....	....	....	1603	33
33	9	....	8	7	1095	19	10	7	1.70	2.04	2.72	3.40	4.08	4.76	5.44	....	....	....	....	....	....	1470	33
33	....	9	8	7	1376	19	10	7	1.23	1.48	1.97	2.46	2.95	3.44	3.94	4.43	5.17	....	....	....	....	2032	33
33	10	....	9	8	1308	19	10	7	1.14	1.37	1.82	2.28	2.74	3.19	3.65	4.10	4.79	5.47	....	....	....	2023	33
33	....	10	9	8	1579	19	10	7	0.89	1.07	1.42	1.78	2.14	2.49	2.85	3.20	3.74	4.27	....	....	....	2643	33

TUBULAR STEEL POLES—DEFLECTIONS AND LOADS.—*Concluded*

Description of poles									Pole set 6 ft. 0 in. in ground—load applied and deflection measured 18 in. from free end, probable deflections when held and loaded as stated													Greatest safe load in lb.	Length in ft.
Length in ft.	Size and kind of pipe				Weight of pole	Section lengths—ft.			Top line gives loads in lb. applied 18 in. from free end of pole														
	Butt		Middle	Top																			
	Std.	Ex. Hvy.	Std.	Std.		Butt	Middle	Top	500	600	800	1000	1200	1400	1600	1800	2100	2400	2700	3000	3300		
34	5	....	4	3	453	20	10	7	....	....	....	....	....	....	....	....	....	....	....	....	....	406	34
34	....	5	4	3	576	20	10	7	....	....	....	....	....	....	....	....	....	....	....	....	....	467	34
34	6	....	5	4	601	20	10	7	7.33	....	....	....	....	....	....	....	....	....	....	....	....	534	34
34	....	6	5	4	793	20	10	7	5.30	6.35	....	....	....	....	....	....	....	....	....	....	....	740	34
34	7	....	6	5	763	20	10	7	4.43	5.32	7.09	....	....	....	....	....	....	....	....	....	....	800	34
34	....	7	6	5	1053	20	10	7	2.89	3.47	4.62	5.78	....	....	....	....	....	....	....	....	....	1130	34
34	8	....	7	6	939	20	10	7	2.84	3.41	4.54	5.68	....	....	....	....	....	....	....	....	....	1057	34
34	....	8	7	6	1236	20	10	7	1.95	2.34	3.12	3.90	4.68	5.46	....	....	....	....	....	....	....	1542	34
34	9	....	8	7	1128	20	10	7	1.90	2.28	3.04	3.80	4.56	5.32	....	....	....	....	....	....	....	1362	34
34	....	9	8	7	1425	20	10	7	1.38	1.65	2.20	2.75	3.30	3.85	4.40	4.95	....	....	....	....	....	1952	34
34	10	....	9	8	1345	20	10	7	1.28	1.53	2.04	2.55	3.06	3.57	4.08	4.59	5.38	....	....	....	....	1947	34
34	....	10	9	8	1634	20	10	7	0.97	1.16	1.55	1.94	2.33	2.72	3.10	3.49	4.07	4.66	....	....	....	2543	34
35	5	....	4	3	468	21	10	7	....	....	....	....	....	....	....	....	....	....	....	....	....	391	35
35	....	5	4	3	597	21	10	7	....	....	....	....	....	....	....	....	....	....	....	....	....	459	35
35	6	....	5	4	620	21	10	7	8.20	....	....	....	....	....	....	....	....	....	....	....	....	515	35
35	....	6	5	4	822	21	10	7	5.59	6.70	....	....	....	....	....	....	....	....	....	....	....	713	35
35	7	....	6	5	786	21	10	7	4.95	5.94	....	....	....	....	....	....	....	....	....	....	....	770	35
35	....	7	6	5	1091	21	10	7	3.23	3.87	5.16	6.45	....	....	....	....	....	....	....	....	....	1,087	35
35	8	....	7	6	968	21	10	7	3.16	3.80	5.06	6.34	....	....	....	....	....	....	....	....	....	1019	35
35	....	8	7	6	1279	21	10	7	2.18	2.61	3.48	4.35	5.22	....	....	....	....	....	....	....	....	1486	35
35	9	....	8	7	1162	21	10	7	2.16	2.59	3.44	4.31	5.17	....	....	....	....	....	....	....	....	1,362	35
35	....	9	8	7	1474	21	10	7	1.53	1.83	2.44	3.05	3.66	4.27	4.88	5.49	....	....	....	....	....	1885	35
35	10	....	9	8	1389	21	10	7	1.31	1.57	2.10	2.63	3.16	3.68	4.20	4.73	....	....	....	....	....	1886	35
35	....	10	9	8	1688	21	10	7	1.09	1.30	1.74	2.18	2.62	3.05	3.48	3.92	4.58	5.13	....	....	....	2451	35

STEEL PIPE TABLE

Nominal diameter in inches	5		6		7		8		9		10	
Weight of pipe	Standard	Extra heavy	Standard	Extra heavy	Standard	Extra heavy	Standard	Extra heavy	Standard	Extra heavy	Standard	Extra heavy
Pounds per foot	14.50	20.54	18.76	28.58	23.27	37.67	28.18	43.00	33.70	48.136	40.06	54.072
Actual diameters												
External = D	5.563	5.563	6.625	6.625	7.625	7.625	8.625	8.625	9.625	9.625	10.750	10.750
Internal = d	5.045	4.813	6.065	5.759	7.023	6.625	7.981	7.625	8.937	8.625	10.018	9.750
Thickness—inches	0.259	0.375	0.280	0.437	0.301	0.500	0.322	0.500	0.344	0.500	0.366	0.500
Circumference												
External	17.477	17.477	20.813	20.813	23.955	23.955	27.096	27.096	30.238	30.238	33.772	33.772
Internal	15.849	15.120	19.054	18.067	22.063	20.813	25.073	23.955	28.076	27.096	31.472	30.631
Transverse areas												
External—sq. in.	24.306	24.306	34.472	34.472	45.664	45.664	58.426	58.426	72.760	72.760	90.763	90.763
Internal—sq. in.	19.985	18.193	28.886	25.976	38.743	34.472	50.021	45.664	62.722	58.426	78.822	74.662
Metal—sq. in.	4.321	6.113	5.586	8.496	6.921	11.192	8.405	12.762	10.04	14.334	11.94	16.101
D^4	957.714	957.714	1,926.386	1,926.386	3,380.009	3,380.009	5,533.965	5,533.965	8,582.285	8,582.285	13,354.690	13,354.690
d^4	647.805	536.615	1,353.079	1,101.517	2,432.711	1,926.386	4,057.226	3,380.009	6,390.640	5,533.965	10,080.240	9,037.879
D^3	172.157	172.157	290.775	290.775	443.322	443.322	641.619	641.619	891.666	891.666	1,242.296	1,242.296
Moment of inertia = I $I = 0.0491\ (D^4 - d^4)$	15.216	20.675	28.159	40.501	46.512	71.372	72.507	105.759	107.609	149.672	160.775	211.955
Modulus of section = S $S = 0.0982 \left(D^3 - \frac{d^4}{D}\right)$	5.47062	7.4350	8.64621	12.61958	12.2049	18.72497	16.81341	24.4989	22.477	31.0035	29.91172	39.43358
Moment of resistance Inch-pounds	109,412	148,700	172,924	252,391	244,080	374,499	336,268	489,978	447,157	620,070	598,234	788,671

The above table is figured on tubing having a tensile strength of 45,000 lb. per square inch, an elastic limit of 24,000 lb. per square inch and a modulus of elasticity of 26,000,000. The greatest safe fiber stress is taken at 20,000 lb. per square inch.

In the preceding pole table the following data were used. The lower end of the poles was assumed to be buried 6 ft. 0 in. in the ground. Moment of inertia = $I = 0.0491\ (D^4 - d^4)$.

The deflections were measured and the load was applied 18 in. from the free end of the pole.

$$\text{Deflection} = x = \frac{PL^3}{3EI}.$$

Where P = load applied 18 in. from the free end. l = length of the pole in inches from the ground line to the point where the load is applied. I = moment of inertia and E = modulus of elasticity.

Class B. For span or bracket construction where spans are not more than 35 ft., or bracket line construction carrying two transmission circuits, one feeder arm, and two telephone and signal arms.

Class C. For constructing telephone, signal and other light auxiliary lines where no side strain is required.

Chestnut Poles

MINIMUM DIMENSIONS OF CHESTNUT POLES IN INCHES
(A.E.R.E.A. STANDARD)

Length of poles (feet)	Class A*		Class B*		Class C*	
	Circumference		Circumference		Circumference	
	Top (inches)	Six feet from butt (inches	Top (inches)	Six feet from butt (inches)	Top (inches)	Six feet from butt (inches)
25	24	36	21	31	20	30
30	24	40	22	36	20	33
35	24	43	22	40	20	36
40	24	45	22	43	20	40
45	24	48	22	47	20	43
50	24	51	22	50	20	46
55	22	54	22	53	20	49
60	22	57	22	56	....	....
65	22	60	22	59	....	....
70	22	63	22	62	....	....
75	22	66	22	65	....	....

* See page 625.

Quality of Chestnut Poles at Time of Delivery. A pole should not have been cut over 2 years, nor should it have been cut when dead. It should not be shaved, nor should it have a crack or large season checks or short crook or a crook or sweep in two planes, or a short reverse curve. Poles over 30 ft. in length should have less sweep than the shorter poles and as follows (A.E.R.E.A. Standard):

Length	Sweep not over
35 ft.	10 in.
40 ft.	11 in.
45 ft.	10 in.
50 ft.	11 in.
55 ft.	12 in.
60 ft.	13 in.
65 ft.	14 in.
70 ft.	15 in.

The sweep is measured between the 6 ft. mark and the top of the pole.

All poles should have sound tops. Poles with double tops should be examined carefully for split tops or rot where the two parts join. All poles should have reasonably sound butts. Hollow butts should be carefully examined, and poles having them rejected, if the hole runs over 4 ft. Poles with hollow butts should be rejected if there is evidence of decay at the further end of the hole inside the pole. There should be no sap rot. There should be no "cat faces" unless they are sound and small and the pole has an increased diameter at the "cat face." There should be no "cat faces" near the 6 ft. mark or within 10 ft. of the top. Poles should be examined carefully for black knots, hollow knots or projections caused by overgrown knots. Overgrown knots should be trimmed off and examined for internal rot. There should be no evidence of rot at knot holes nor should there be large hollow knots. There should be no top, butt or black knot which has been plugged. The pole should be free from woodpeckers' holes or evidence of ants, worms or grubs.

Eastern White Cedar Poles

MINIMUM DIMENSIONS OF EASTERN WHITE CEDAR POLES IN INCHES (A.E.R.E.A. STANDARD)

Length of poles (feet)	Class A*		Class B*		Class C*	
	Circumference		Circumference		Circumference	
	Top (inches)	Six feet from butt (inches)	Top (inches)	Six feet from butt (inches)	Top (inches)	Six feet from butt (inches)
30	24	40	22	36	18¾	33
35	24	43	22	38	18¾	36
40	24	47	22	43	18¾	40
45	24	50	22	47	18¾	43
50	24	53	22	50	18¾	46
55	24	56	22	53	18¾	49
60	24	59	22	56	....	....

* See page 625.

Poles should be of the best quality of either seasoned or live green cedar of dimensions given in the above table. Seasoned poles should have preference over green poles, provided they have not been held for seasoning long enough to have developed any objectionable timber defects. They should be reasonably straight, well proportioned from butt to top, both ends squared, the bark peeled and all knots and limbs closely trimmed. They should not be shaved. A pole should not have dead streaks covering more than one-quarter of its surface. A dead pole or one having dead streaks covering more than one-quarter of its surface should be rejected. A pole having dead streaks covering less than one-quarter of it surface should have a circumference greater than otherwise required. This increase in the circumference should be sufficient to afford a cross-sectional area of sound wood equivalent to that of a pole of the same class.

Fire Killed or River Poles. No dark red or copper colored pole which, when scraped, does not show good live timber should be accepted. No pole should have more than one complete twist for every 20 ft. in length nor should it have a large season check. There should be no "cat faces" unless they are small and perfectly sound and the poles have an increased diameter at the "cat faces, nor have "cat faces" near the 6 ft. mark or within 10 ft. of the top. A pole should contain no sap rot, evidence of internal rot as disclosed by a careful examination. There should be no black knots, hollow knots, woodpeckers' holes, or plugged holes, and no pole should show evidence of having been eaten by ants, worms or grubs, except that poles containing worm or grub marks below the 6 ft. mark may be accepted. A pole should have a sound top with no pencil holes. A pole having a double top of double heart should be free from rot where the two parts or hearts join. A pole should be free from ring rot (rot in the form of a complete or partial ring). A pole should not have a short crook or bend, a crook or bend in two planes or a reverse curve. The amount of sweep, measured between the 6 ft. mark and the top of the pole, that may be present in poles, is shown in the following table (A.E.R.E.A. Standard):

Length	Sweep not over
35 ft.	10½ in.
40 ft.	12 in.
45 ft.	10 in.
50 ft.	10 in.
55 ft.	11 in.
60 ft.	12 in.

Poles may have hollow hearts under the conditions shown in the following table which is Standard of the A.E.R.E.A.:

Average diameter of hollow heart	Add to butt requirements of		
	30 ft. poles	35, 40 and 45 ft. poles	50, 55, 60 and 65 ft. poles
2-in.	Nothing	Nothing	Nothing
3-in.	1-in.	Nothing	Nothing
4-in.	2-in.	Nothing	Nothing
5-in.	3-in.	1-in.	Nothing
6-in.	4-in.	2-in.	1-in.
7-in.	Reject	4-in.	2-in.
8-in.	Reject	6-in.	3-in.
9-in.	Reject	Reject	4-in.
10-in.	Reject	Reject	5-in.
11-in.	Reject	Reject	7-in.
12-in.	Reject	Reject	9-in.
13-in.	Reject	Reject	Reject

Scattered rot, unless it is near the outside of the pole, may be estimated as being the same as heart rot of equal area. Poles with cup shakes (checks in the form of rings) which also have heart or star checks may be considered as equal to poles having hollow hearts of the average diameter of the cup shakes.

Western White Cedar Poles

("Red Cedar," "Western Cedar," or "Idaho Cedar")

MINIMUM DIMENSIONS OF WESTERN WHITE CEDAR POLES IN INCHES—(CIRCUMFERENCE). A.E.R.E.A. STANDARD

Length of poles (feet)	Class A*	Class B*	Class C*
	Top 28	Top 25	Top 22
	Butt	Butt	Butt
30	37	34	30
35	40	36	32
40	43	38	34
45	45	40	36
50	47	42	38
55	49	44	40
60	52	46	41
65	54	48	43

* See page 625.

NOTE: "Top" measurement being the circumference at the top of the pole, and the "butt" measurement, the circumference 6 ft. from the butt.

Poles should be of the best quality of either seasoned or live green cedar. Seasoned poles should have preference over green poles, provided they have not been held for seasoning long enough to have developed any objectionable timber defects. Poles should be reasonably straight, well proportioned from butt to top, both ends squared, sound tops, the bark peeled, and all knots and limbs closely trimmed. Large knots, if sound and trimmed close, should not be considered a defect. A pole should not contain hollow or rotten knots, nor should it contain sap rot, woodpeckers' holes, or plugged holes, nor show evidence of having been eaten by ants, worms or grubs. A pole should not be dead nor should it have dead streaks covering more than one-quarter of its surface. A pole having dead streaks covering less than one-quarter of its surface should have a circumference greater than otherwise required. The increase in the circumference should be sufficient to afford a cross-sectional area of sound wood equivalent to that of a sound pole of the same class. A pole should not have more than one complete twist for every 20 ft. in length nor should it have a large season check or crack. No pole should have a short crook or bend, a crook or bend in two planes, or a reverse crook or bend. The amount of sweep measured between the 6 ft. mark and the top of the pole should not exceed 1 in. to every 6 ft. in length. A pole should have no "cat faces," unless they are small and perfectly sound and the pole has an increased diameter at the "cat face," nor have "cat faces" near the 6 ft. mark, or within 10 ft. of its top. A pole having cup shakes (checks in the form of rings) should contain no heart or star shakes which enclose more than 10 per cent. of the area of the butt. A pole should not have butt rot covering in excess of 10 per cent. of the total area of the butt. The butt rot, if present, must be located close to the center.

Reinforced Concrete Poles. Fig. 29 and the following formulas are from the report of the Committee on Power Distribution, A.E.R.E.A., 1914. The square section is more efficient and economical than either the hexagonal or the octagonal. The two latter were developed for situations in which the square pole would not present a sufficiently artistic appearance.

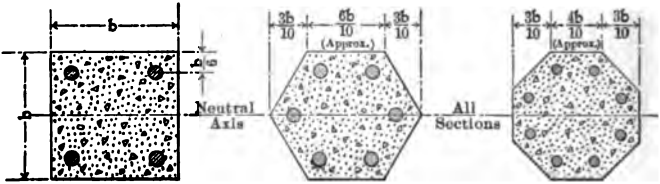


FIG. 29.—Proposed sections for concrete poles.

Square

Deflection $x = \frac{30Pl^3}{E_s b^4}$

Area $= b^2$

Safe load, $P_1 = \frac{1750d^2b}{L}$ (Approx.)

Hexagonal

$x = \frac{40Pl^3}{E_s b^4}$

Area $= \frac{9b^2}{10}$ (Approx.)

$P_2 = \frac{9P_1}{10}$

$= \frac{1575d^2b}{L}$ (Approx.)

Octagonal.

$x = \frac{47Pl^3}{E_s b^4}$

Area $= \frac{8b^2}{10}$ (Approx.)

Safe load, $P_3 = \frac{8P_1}{10}$

$= \frac{1400d^2b}{L}$ (Approx.)

In which

x = deflection at a point 18 in. below top of pole, inches. (See note below)
P = horizontal pull at a point 18 in. below top of pole, pounds
l = length of pole from point of application of P to the ground line (6 ft. from base end), inches
L = length of pole from point of application of P to the ground line (6 ft. from base end), feet
E_s = modulus of elasticity of steel used
b = side of square pole or distance between parallel faces of hexagonal or octagonal pole at ground line, inches
d = diameter of steel rods, inches

Four per cent. of steel used in all sections.

NOTE: The above report states that coefficients 30, 40 and 47 of the formulas for deflection, respectively, should be increased per cent. for practical application. Relative to the coefficient for square poles the 1913 committee states: "Further investigation shows that when the concrete is assumed not cracked at all on the tension edge the constant may reduce to 25 approximately, and that for concrete cracked to center of pole and neutral axis at center, the constant may increase to 70, approximately. The taper of the pole will also tend to increase this constant. Hence it can only be concluded roughly that the above formula may give the deflections for certain assumptions, but that the range of variation might, under unusual conditions, range from 33 per cent. less to 100 per cent. more than the values (30, 40 or 47) given in the formulas."

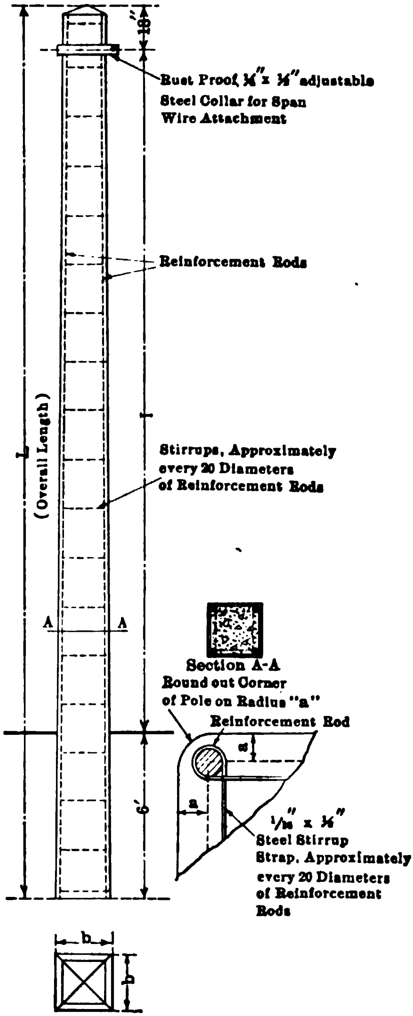

18"
Rust Proof, ¼" x ½" adjustable Steel Collar for Span Wire Attachment
Reinforcement Rods
L
(Overall Length)
Stirrups, Approximately every 20 Diameters of Reinforcement Rods
A
A
Section A-A
Round out Corner of Pole on Radius "a"
Reinforcement Rod
a
a
6'
1/16" x ½" Steel Stirrup Strap, Approximately every 20 Diameters of Reinforcement Rods
b
b

Fig. 30.—Proposed design for square concrete pole.

The values in the table (pp. 637 to 639) from the "Miscellaneous Practice" of the American Electric Railway Engineering Association are calculated on the proposed design of a reinforced-concrete pole of square cross-section, shown in Fig. 30.

Manufacture of Reinforced Concrete Poles. The New York State Railways Co. is successfully manufacturing four standard sizes of reinforced concrete poles as follows: (1) 7 in. top, 30 ft. the standard trolley pole for city construction either bracket

REINFORCED CONCRETE POLES—DEFLECTIONS AND LOADS

Length feet	Description of pole			Weight of pole in lb.	Probable deflection in inches at point of application of load—18 in. from top, with pole 6 ft. 0 in. in ground															Greatest safe load in lb.	Length feet
	Butt section	Top section	Diameter reinforcement		100	200	400	600	800	1,000	1,200	1,400	1,600	1,800	2,100	2,400	2,700	3,000	3,300		
	(In.)	(In.)	(In.)																		
28	5×5	3×3	9/16	525	2.7	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	121	28
28	6×6	4×4	5/8	812	1.5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	190	28
28	7×7	5×5	3/4	1176	0.825	1.650	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	330	28
28	8×8	6×6	1	1624	0.435	0.870	1.755	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	683	28
28	9×9	7×7	1-1/8	2128	0.280	0.561	1.122	1.686	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	988	28
28	10×10	8×8	1-1/4	2688	0.180	0.360	0.720	1.080	1.440	1.800	.....	.....	.....	.....	.....	.....	.....	.....	.....	1372	28
28	11×11	9×9	1-3/8	3304	0.127	0.255	0.510	0.765	1.020	1.275	1.530	1.785	.....	.....	.....	.....	.....	.....	.....	1844	28
28	12×12	10×10	1-1/2	4090	0.090	0.180	0.360	0.540	0.720	0.900	1.080	1.260	1.440	1.605	.....	.....	.....	.....	.....	2415	28
28	13×13	11×11	1-5/8	4746	0.066	0.133	0.267	0.400	0.534	0.669	0.802	0.936	1.068	1.230	1.404	1.605	.....	.....	.....	3091	28
28	14×14	12×12	1-3/4	5558	0.048	0.096	0.195	0.292	0.390	0.486	0.585	0.675	0.780	0.876	1.020	1.179	1.314	1.458	1.605	3884	28
29	5×5	3×3	9/16	544	3.3	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	115	29
29	6×6	4×4	5/8	841	1.605	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	182	29
29	7×7	5×5	3/4	1218	0.864	1.726	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	314	29
29	8×8	6×6	1	1682	0.510	1.005	2.010	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	651	29
29	9×9	7×7	1-1/8	2204	0.315	0.630	1.260	1.905	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	942	29
29	10×10	8×8	1-1/4	2784	0.214	0.429	0.855	1.275	1.710	2.145	.....	.....	.....	.....	.....	.....	.....	.....	.....	1308	29
29	11×11	9×9	1-3/8	3422	0.150	0.315	0.615	0.915	1.230	1.515	1.830	2.145	.....	.....	.....	.....	.....	.....	.....	1758	29
29	12×12	10×10	1-1/2	4232	0.105	0.210	0.420	0.610	0.840	1.050	1.260	1.470	1.680	1.890	.....	.....	.....	.....	.....	2302	29
29	13×13	11×11	1-5/8	4915	0.075	0.150	0.300	0.450	0.600	0.750	0.885	1.035	1.185	1.320	1.545	1.770	.....	.....	.....	2945	29
29	14×14	12×12	1-3/4	5756	0.052	0.105	0.210	0.322	0.426	0.640	0.645	0.750	0.855	0.960	1.123	1.284	1.444	1.605	.....	3706	29
29	15×15	13×13	1-7/8	6670	0.040	0.082	0.165	0.247	0.330	0.405	0.495	0.542	0.660	0.742	0.862	0.985	1.108	1.231	1.354	4578	29
30	5×5	3×3	9/16	562	3.904	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	112	30
30	6×6	4×4	5/8	870	1.875	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	174	30
30	7×7	5×5	3/4	1260	1.005	2.010	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	300	30
30	8×8	6×6	1	1740	0.570	1.140	2.280	3.480	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	622	30

REINFORCED CONCRETE POLES—DEFLECTIONS AND LOADS.—*Continued*

Length feet	Description of pole			Weight of pole in lb.	Probable deflection in inches at point of application of load—18 in. from top, with pole 6 ft. 0 in. in ground															Greatest safe load in lb.	Length feet
	Butt section	Top section	Diameter reinforcement		100	200	400	600	800	1,000	1,200	1,400	1,600	1,800	2,100	2,400	2,700	3,000	3,300		
	(In.)	(In.)	(In.)																		
30	10×10	8×8	1-1/4	2880	0.240	0.480	0.972	1.458	1.944	2.430	2.910	.....	.....	.....	.....	.....	.....	.....	.....	1250	30
30	11×11	9×9	1-3/8	3540	0.166	0.333	0.666	0.999	1.332	1.665	1.998	2.331	2.664	.....	.....	.....	.....	.....	.....	1680	30
30	12×12	10×10	1-1/2	4275	0.117	0.234	0.468	0.702	0.936	1.173	1.404	1.638	1.872	2.106	2.463	.....	.....	.....	.....	2200	30
30	13×13	11×11	1-5/8	5091	0.078	0.156	0.312	0.468	0.624	0.784	0.936	1.092	1.248	1.404	1.638	1.872	2.118	.....	.....	2816	30
30	14×14	12×12	1-3/4	5955	0.063	0.126	0.252	0.378	0.504	0.630	0.756	0.882	1.008	1.134	1.323	1.512	1.701	1.890	2.079	3539	30
31	5×5	3×3	9/16	580	4.440	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	108	31
31	6×6	4×4	5/8	899	2.130	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	167	31
31	7×7	5×5	3/4	1302	1.125	2.265	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	287	31
31	8×8	6×6	1	1798	0.645	0.129	2.580	3.885	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	596	31
31	9×9	7×7	1-1/8	2356	0.390	0.795	1.590	2.535	3.210	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	862	31
31	10×10	8×8	1-1/4	2976	0.277	0.555	1.110	1.665	2.370	2.775	3.337	.....	.....	.....	.....	.....	.....	.....	.....	1197	31
31	11×11	9×9	1-3/8	3658	0.190	0.381	0.765	1.140	1.665	1.905	2.280	2.667	3.330	.....	.....	.....	.....	.....	.....	1609	31
31	12×12	10×10	1-1/2	4418	0.133	0.267	0.540	0.795	1.065	1.335	1.770	1.870	2.145	2.403	2.805	.....	.....	.....	.....	2107	31
31	13×13	11×11	1-5/8	5247	0.094	0.190	0.375	0.570	0.780	0.954	1.161	1.335	1.560	1.719	2.010	2.331	2.580	.....	.....	2697	31
31	14×14	12×12	1-3/4	6154	0.070	0.141	0.300	0.420	0.600	0.708	0.849	1.005	1.200	1.273	1.475	1.800	1.905	2.124	2.340	3388	31
31	15×15	13×13	1-7/8	7130	0.054	0.109	0.225	0.330	0.435	0.549	0.660	0.765	0.891	0.990	1.155	1.314	1.435	1.647	1.815	4190	31
32	5×5	3×3	9/16	500	5.040	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	103	32
32	6×6	4×4	5/8	928	2.415	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	159	32
32	7×7	5×5	3/4	1344	1.312	2.625	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	276	32
32	8×8	6×6	1	1856	0.750	1.500	3.000	4.500	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	571	32
32	9×9	7×7	1-1/8	2432	0.484	0.969	1.935	2.895	3.720	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	827	32
32	10×10	8×8	1-1/4	3072	0.315	0.630	1.260	1.890	2.520	3.151	.....	.....	.....	.....	.....	.....	.....	.....	.....	1148	32
32	11×11	9×9	1-3/8	3776	0.214	0.429	0.855	1.287	1.710	2.158	2.574	3.003	.....	.....	.....	.....	.....	.....	.....	1543	32
32	12×12	10×10	1-1/2	4560	0.151	0.303	0.606	0.909	1.212	1.515	1.818	2.121	2.424	2.727	.....	.....	.....	.....	.....	2020	32
32	13×13	11×11	1-5/8	5416	0.108	0.216	0.432	0.648	0.864	1.081	1.296	1.512	1.728	1.944	2.269	2.592	.....	.....	.....	2586	32
32	14×14	12×12	1-3/4	6452	0.082	0.163	0.327	0.490	0.654	0.817	0.981	1.144	1.308	1.471	1.716	1.962	2.200	2.452	2.700	3250	32
32	15×15	13×13	1-7/8	7360	0.062	0.124	0.249	0.373	0.498	0.622	0.747	0.871	0.996	1.120	1.306	1.479	1.68	1.867	2.055	4018	32

REINFORCED CONCRETE POLES—DEFLECTIONS AND LOADS.—*Concluded*

33	5×5	3×3	9/16	619	5.670	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	100	33
33	6×6	4×4	5/8	957	2.725	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	153	33
33	7×7	5×5	3/4	1386	1.455	2.925	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	261	33
33	8×8	6×6	1	1914	0.825	1.665	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	549	33
33	9×9	7×7	1-1/8	2508	0.540	1.080	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	794	33
33	10×10	8×8	1-1/4	3168	0.354	0.693	1.386	2.079	2.772	3.540	.....	.....	.....	.....	.....	.....	.....	.....	.....	1078	33
33	11×11	9×9	1-3/8	3894	0.243	0.486	0.970	1.456	1.941	2.428	2.763	3.390	.....	.....	.....	.....	.....	.....	.....	1480	33
33	12×12	10×10	1-1/2	4702	0.169	0.339	0.678	1.017	1.356	1.704	2.034	2.373	2.712	3.051	.....	.....	.....	.....	.....	1940	33
33	13×13	11×11	1-5/8	5577	0.121	0.243	0.486	0.729	0.972	1.215	1.458	1.701	1.943	2.178	2.547	2.916	.....	.....	.....	2480	33
33	14×14	12×12	1-3/4	6550	0.093	0.184	0.369	0.553	0.738	0.924	1.107	1.291	1.476	1.660	1.939	2.220	2.490	2.775	.....	3122	33
33	15×15	13×13	1-7/8	7590	0.070	0.141	0.297	0.420	0.561	0.702	0.840	0.981	1.122	1.260	1.470	1.680	1.890	2.100	2.310	3860	33
34	5×5	3×3	9/16	637	6.370	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	96	34
34	6×6	4×4	5/8	986	3.075	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	147	34
34	7×7	5×5	3/4	1428	1.560	3.120	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	255	34
34	8×8	6×6	1	1922	0.900	1.800	3.600	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	527	34
34	9×9	7×7	1-1/8	2584	0.600	1.200	2.400	3.600	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	764	34
34	10×10	8×8	1-1/4	3264	0.397	0.795	1.590	2.385	3.180	3.970	.....	.....	.....	.....	.....	.....	.....	.....	.....	1037	34
34	11×11	9×9	1-3/8	4012	0.271	0.543	1.086	1.629	2.172	2.710	3.258	3.810	.....	.....	.....	.....	.....	.....	.....	1427	34
34	12×12	10×10	1-1/2	4845	0.192	0.384	0.768	1.140	1.536	1.920	2.295	2.685	3.072	3.450	.....	.....	.....	.....	.....	1868	34
34	13×13	11×11	1-5/8	5755	0.136	0.273	0.546	0.822	1.092	1.371	1.644	1.918	2.184	2.467	2.862	3.288	.....	.....	.....	2400	34
34	14×14	12×12	1-3/4	6749	0.103	0.207	0.399	0.621	0.799	1.030	1.237	1.449	1.650	1.860	2.175	2.475	2.790	3.100	.....	3005	34
34	15×15	13×13	1-7/8	7820	0.079	0.159	0.319	0.480	0.639	0.780	0.960	1.125	1.275	1.440	1.680	1.920	2.160	2.400	2.640	3715	34
35	5×5	3×3	9/16	656	7.120	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	93	35
35	6×6	4×4	5/8	1015	3.420	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	142	35
35	7×7	5×5	3/4	1470	1.845	3.690	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	245	35
35	8×8	6×6	1	2030	1.059	2.110	4.230	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	508	35
35	9×9	7×7	1-1/8	2660	0.684	1.365	2.730	4.110	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	736	35
35	10×10	8×8	1-1/4	3360	0.445	0.885	1.770	2.655	3.540	4.455	.....	.....	.....	.....	.....	.....	.....	.....	.....	999	35
35	11×11	9×9	1-3/8	4130	0.304	0.610	1.230	1.845	2.460	3.060	3.690	4.305	.....	.....	.....	.....	.....	.....	.....	1375	35
35	12×12	10×10	1-1/2	4988	0.213	0.420	0.840	1.260	1.680	2.145	2.520	2.940	3.360	3.780	.....	.....	.....	.....	.....	1800	35
35	13×13	11×11	1-5/8	5924	0.151	0.300	0.600	0.900	1.200	1.530	1.800	2.100	2.400	2.700	3.180	.....	.....	.....	.....	2304	35
35	14×14	12×12	1-3/4	6948	0.115	0.210	0.420	0.630	0.840	1.155	1.260	1.470	1.680	1.890	2.430	2.520	3.225	.....	.....	2895	35
35	15×15	13×13	1-7/8	8050	0.087	0.180	0.360	0.540	0.720	0.885	1.080	1.260	1.440	1.620	1.845	2.160	2.370	2.490	2.730	3580	35

or span; (2) 7 in. top, 35 ft. long, for interurban work; (3) 8 in. top, 30 ft. long, for heavy city construction; (4) 8 in. top, 45 ft. long, for feeder lines. The poles are cast in molds consisting of three 2-in. Georgia pine planks. The side planks are clamped in position by means of 2 × 4 in. notched sticks. The chamfer of the pole corners is provided by strips of triangular cross-section nailed inside the side planks. Pieces of round iron are inserted wherever holes in the pole are required. The gains are made by blocks nailed in the proper places. The concrete mixture consists of one part cement, two parts sand and two parts broken stone of ⅝ in. to ¾ in. size. The concrete is mixed by hand and transported in a hopper of 1 ton capacity handled by a crane. The standard 7 in. × 30 ft. pole has the following reinforcing: twisted steel rods placed about 1 in. from the surface—four ⅝ in. × 29½ ft., four ½ in. × 23 ft., four ½ in. × 16 ft., and four ½ in. × 8 ft. The arrangement of this reinforcing is shown by Fig. 31. This pole weighs approximately 3200 lb. and costs complete, including all material and labor, maintenance of plant, etc., $12.03 at the place of manufacture. Fig. 32 shows the details of construction of the wooden forms for this pole. The poles with 8-in. tops have the same arrangement of rods, all of which are ⅝ in. instead of ½ in. The longer poles have the rods lengthened at the top ends. The specifications for the concrete forms and the instructions for casting the poles are given below.

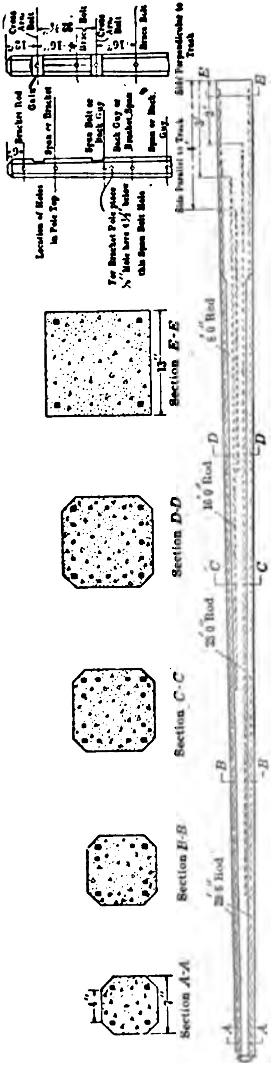


FIG. 31.—Details of concrete pole—Syracuse.

Specifications for Forms for Concrete Poles

This form to be built of hard pine and chamfer strips to be put on with screws and finishing nails. Side cleats to be bolted.

Chamfer strips to be placed on side sections of form. Gain block placed on bottom section; if chamfer strips

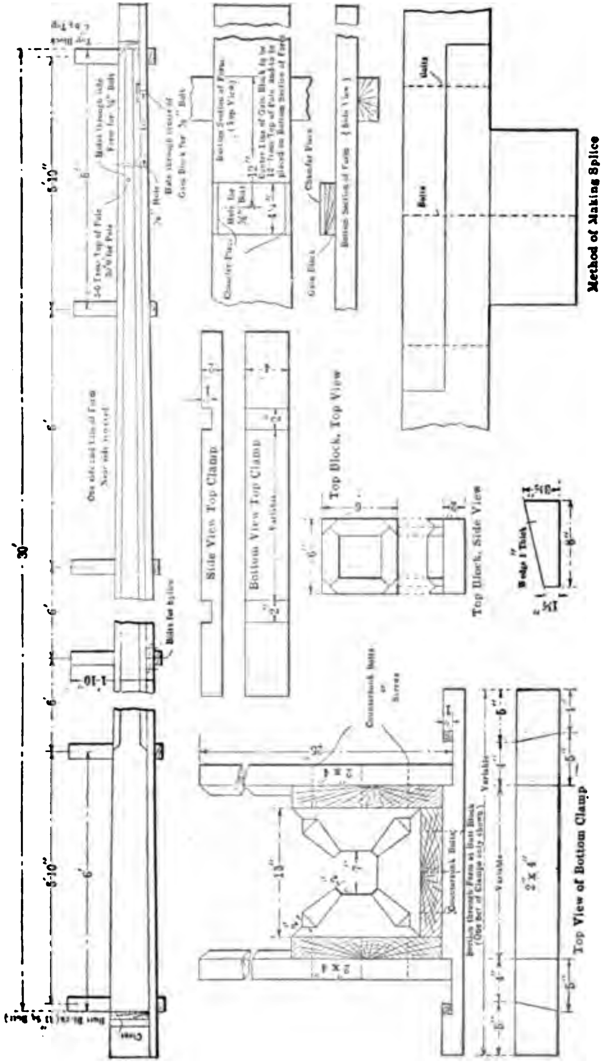


FIG. 32.—Details of wooden forms for concrete poles—Syracuse.

come higher than gain block, two small strips are to be placed on gain block as shown.

Forms should be oiled before using, inside and out, with raw linseed oil. Holes through pole for bolts should be made by blank bolts, same size as hole, embedded in concrete through form and pulled out 2 days after casting pole. Bolts should be loosened by turning slightly 6 hours after pole is cast.

Instructions for Casting Concrete Poles

Before casting poles oil form inside with a mixture of one part black oil and one part gasoline. This oiling to be done immediately before casting pole.

The concrete mixture to be formed from one part cement, two parts sand and two parts stone, measurement to be made by volume.

All stone used to be clean and free from loam or dirt. Thoroughly wet the stone in the pile before mixing.

Sand to be free from loam or dirt. Place the proper amount of sand on the mixing board and spread out to a thickness of 4 in. On this sand place the cement and turn both three times, after which apply the water and turn so that the mass is entirely wet. Spread out this mortar again in a 4-in. layer and dump the stone in another layer on top. Turn the mortar and stone until mortar and stone are thoroughly intermixed. The concrete mixture must not be left on the board long enough to require retempering, but should be placed in the forms at once.

In placing the reinforcing rods great care must be used to properly locate them and maintain in the proper position.

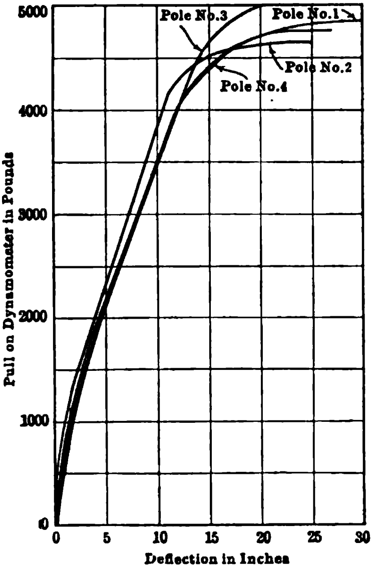


FIG. 33.—Tests on reinforced concrete poles.

The time of removing of side forms and moving of pole to storage will vary with the weather, but in no case shall a pole be lifted until ninety-six hours have elapsed after casting. After removal from the forms the pole shall be painted with a mixture of one part cement and one part sand, the pole being wet before the application of this paint.

Remember that a crack formed in a pole by handling the pole when it is too green cannot be healed.

In the storage and shipping of poles 2-in. cleats must be placed between the separate horizontal layers of poles to allow attachment of clamps for handling.

Tests of Concrete Poles. From tests on reinforced concrete poles carried on under the direction of Mr. W. R. Molinard, Oklahoma Gas and Electric Co. and Mr. H. M. Fisher, Nashville Railway and Light Co. it was concluded that hollow poles are not successful in resisting shearing forces from the ground line down, as all showed shearing failure in this region. After failure the tendency of the concrete on the compression side was to slide by that on the tension side, causing a shearing action in the side walls. Poles having few bars with some butt reinforcement were shown to be preferable. Hollow poles are more expensive than solid ones, they are more difficult to make and are not much lighter for equal strength.

Fig. 33 shows stress-strain diagrams derived from tests on reinforced concrete poles carried on under the direction of Mr. Henry G. Throop, New York State Railways. These curves show the deflections of these poles when under various loads and bring out the fact that the changes from the standard method of construction involved in bunching the rods are not justified by the resulting slight increased strength of the poles. These were 7 in. × 30 ft. poles made of a mixture of one part cement, two parts sand and two parts of stone. The reinforcement of pole No. 1 consisted of four ⅝-in. twisted rods 29½ ft. long placed in the corners and four

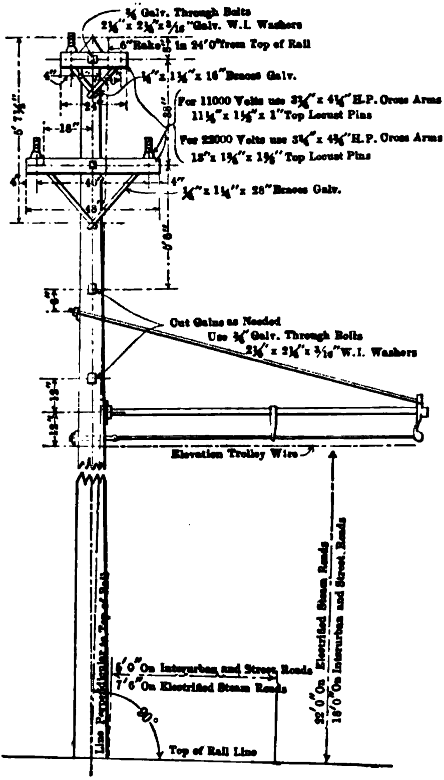

⅝ Galv. Through Bolts
2¼"x 2¼"x 3/16"Galv. W.I. Washers
6"Rake in 24'0"from Top of Rail
¼"x 1¼"x 16"Braces Galv.
For 11000 Volts use 3¼"x 4¼"H.P. Cross Arms
11¼"x 1½"x 1"Top Locust Pins
For 22000 Volts use 3¾"x 4¾"H.P. Cross Arms
13"x 1½"x 1½"Top Locust Pins
¼"x 1¼"x 28"Braces Galv.
5' 7⅛"
24"
18"
38"
4"
40"
48"
4"
5'6"
Cut Gains as Needed
Use ⅝"Galv. Through Bolts
2¼"x 2¼"x 3/16"W.I. Washers
18"
18"
Elevation Trolley Wire
Line Perpendicular to Top of Rails
6'0"On Interurban and Street Roads
7'6"On Electrified Steam Roads
90°
Top of Rail Line
22'0"On Electrified Steam Roads
18'0"On Interurban and Street Roads

FIG. 34.—Typical pole construction, trolley and one transmission line.

½ in. × 23 ft. rods, four ½ in. × 16 ft. rods and four ½ in. × 8 ft. rods evenly spaced along the sides. (See page 640.) The same construction was used in pole No. 4. Pole No. 2 was constructed in the same manner with the exception that three of the center rods on each of the two sides were placed back of the rods on a compression and tension side. Pole No. 3 was constructed in the same

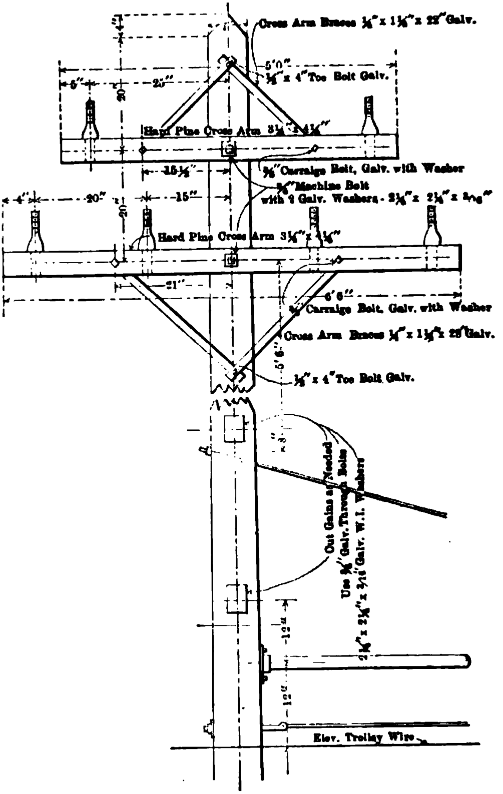

Cross Arm Braces ¼" x 1½" x 22" Galv.
5'0"
½" x 4" Toe Bolt Galv.
5"
25"
20
Hard Pine Cross Arm 3¼" x 4¼"
15½"
⅝" Carriage Bolt, Galv. with Washer
⅝" Machine Bolt with 2 Galv. Washers - 2¼" x 2¼" x 3/16"
4"
20"
15"
20
Hard Pine Cross Arm 3¼" x 4¼"
21"
6'6"
⅝" Carriage Bolt, Galv. with Washer
Cross Arm Braces ¼" x 1½" x 28" Galv.
5'6"
½" x 4" Toe Bolt Galv.
Cut Gains as Needed
Use ⅝" Galv. Through Bolts
2¼" x 2¼" x 3/16" Galv. W.I. Washers
12"
12"
Elev. Trolley Wire

FIG. 35.—Typical pole construction, trolley and two 11,000-volt transmission lines.

manner as pole No. 1 with the exception that a web reinforcement of No. 8 steel wire was wound around the various reinforcing rods at intervals of 5 in. throughout the length of the pole. All the poles were aged from 4 to 4½ months. Poles Nos. 2 and 3 were tested simply to determine whether or not the bunching of reinforcement on the tension and compression sides, or the installation of web reinforcement, would produce enough greater strength or stiffness over the standard method of construction to warrant the expense of the additional reinforcement, or the inconvenience produced by the necessity of placing poles like No. 2 with a bunched reinforcement in such a position that the tension and compression sides would always be perpendicular to the direction of the stress. For testing purposes the poles were set 6 ft. in the ground with a rake of 9 in., and a 2-ft. ring of concrete 1 ft. thick was placed on the ground line and also at the butt. Wooden poles were placed on the ground between the butts of two of the concrete poles so as to maintain the base of the latter in position. In the tests the poles did not move in the ground more than 1/16 in. A 7/16-in. steel cable was connected by means of an eye bolt through the pole under test at a point 21 ft. above the ground line, and a 5000 lb. dynamometer was placed in the cable close to the pole. The cable was passed through a sheave at the same distance from the ground on the pole opposite the one under test. The pull was applied by means of a set of tackle blocks in increments of approximately 200 lb. up to failure. Deflection from the vertical was measured at the point of attachment of the cable by means of a surveyor's transit.

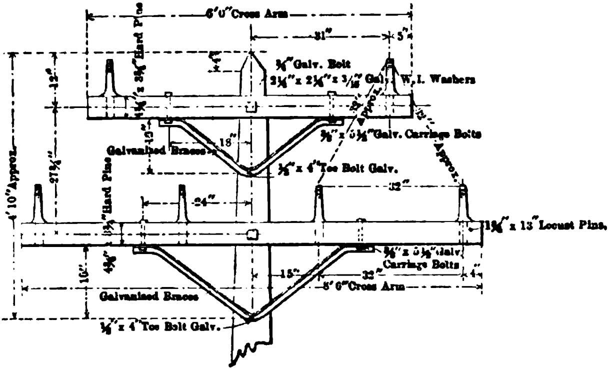


FIG. 36.—Typical pole-top construction, two 22,000-volt transmission lines.

Typical Railway Transmission Line Construction. Figs. 34 to 37, inclusive, show typical 11,000-volt, and 22,000-volt pole line constructions from the practice of the Connecticut Company.

Specifications for Overhead Crossings of Electric Light and Power Lines. (Recommended by the A. E. R. E. A.):

General Requirements. 1. *Scope.* This specification shall apply to Overhead Electric Light and Power Line Crossings (except trolley contact wires), over railroad right-of-way, tracks, or lines of wires; and, further, these specifications shall apply to Overhead Electric Light and Power Wires of over 5000 volts constant potential, crossing telephone, telegraph or other similar lines. It is not intended that these specifications shall apply to crossings over individual twisted pair drop wires, or other circuits of minor importance where equally effective protection may be secured more economically by other methods of construction.

2. *Location.* The poles, or towers, supporting the crossing span preferably shall be outside the railroad company's right-of-way.

3. Unusually long crossing spans shall be avoided wherever practicable, and the difference in length of the crossing and adjoining spans generally shall be not more than 50 per cent. of the length of the crossing span.

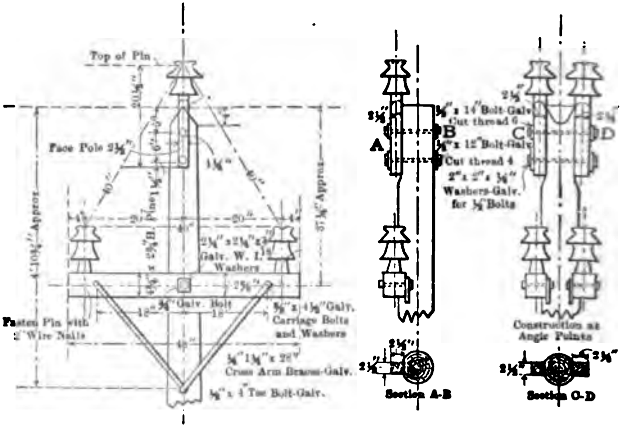

Top of Pin
20⅛"
Face Pole 2⅛"
6"
1⅛"
40"
40"
4"
20"
20"
4"
4'10⅛" Approx.
37⅛" Approx.
Pine 1⅛" H. x 2⅝"
2¼" x 2¼" x 3/16" Galv. W. I. Washers
4⅝"
2⅝"
⅝" Galv. Bolt
12"
18"
⅝" x 4½" Galv. Carriage Bolts and Washers
Fasten Pin with 2" Wire Nails
48"
¼" 1¼" x 28" Cross Arm Braces-Galv.
⅝" x 4" Tee Bolt-Galv.
2⅛"
A
B
⅝" x 14" Bolt-Galv. Cut thread 6
⅝" x 12" Bolt-Galv. Cut thread 4
2" x 2" x ⅛" Washers-Galv. for ⅝" Bolts
2⅛"
C
D
2⅛"
Construction at Angle Points
2⅛"
2⅛"
Section A-B
2⅛"
2⅛"
Section C-D

FIG. 37.—Typical pole-top construction, one 22,000-volt line.

4. The poles, or towers, shall be located as far as practicable from inflammable material or structures.

5. The poles, or towers, supporting the crossing span, and the adjoining span on each side, preferably shall be in a straight line.

6. The wires, or cables, shall cross over telegraph, telephone, and similar wires wherever practicable.

7. Cradles, or overhead bridges, shall not be used beneath the crossing wires or cables; but in cases where the crossing wires or cables cross beneath the railroad wires, telephone, telegraph, or other similar wires, a protection of adequate strength and proper design between the two sets of crossing wires or cables may be required.

8. Unless physical conditions or municipal requirements prevent, the side clearance shall be not less than 12 ft. from the nearest track rail, except that at sidings a clearance of not less than 7 ft. may be allowed. At loading sidings sufficient space shall be left for a driveway.

9. The clear headroom shall be not less than 30 ft. above the top of 'l under the most unfavorable condition of temperature and

loading. For constant potential, direct-current circuits, not exceeding 750 volts, when paralleled by trolley contact wires, the clear headroom need not exceed 25 ft.

10. The clearance of alternating-current circuits above any existing wires, under the most unfavorable condition of temperature and loading, shall be not less than 8 ft. wherever possible. For constant potential, direct-current circuits, not exceeding 750 volts, the minimum clearance above telegraph, telephone, and similar wires may be 2 ft. with insulated wires and 4 ft. with bare wires.

11. The separation of conductors carrying alternating current, supported by pin insulators, for spans not exceeding 150 ft., shall be not less than:

Line voltage	Separation
Not exceeding 7,000 volts	12 in.
Exceeding 7,000, but not exceeding 14,000	20 in.
Exceeding 14,000, but not exceeding 27,000	30 in.
Exceeding 27,000, but not exceeding 35,000	36 in.
Exceeding 35,000, but not exceeding 47,000	45 in.
Exceeding 47,000, but not exceeding 70,000	60 in.

For spans exceeding 150 ft. the pin spacing should be increased, depending upon the length of the span and the sag of the conductors.*

With constant potential direct-current circuits not exceeding 750 volts, the minimum spacing shall be 10 in.

12. When supported by insulators of the disk or suspension type, the crossing span and the next adjoining spans shall be dead ended at the poles, or towers, supporting the crossing span, so that at these poles, or towers, the insulators shall be used as strain insulators, or the height of the wire attachments shall be such that with the maximum sag in the crossing span occurring from failure of the construction outside the crossing span, and taking into account the deflections in the strings of suspension insulators, the minimum clearances, as given in Paragraphs 9 and 10, shall be maintained.

13. The clearance in any direction between the conductors nearest the pole, or tower, and the pole, or tower, shall be not less than:

Line voltage	Clearances
Not exceeding 10,000 volts	9 in.
Exceeding 10,000, but not exceeding 14,000	12 in.
Exceeding 14,000, but not exceeding 27,000	15 in.
Exceeding 27,000, but not exceeding 35,000	18 in.
Exceeding 35,000, but not exceeding 47,000	21 in.
Exceeding 47,000, but not exceeding 70,000	24 in.

14. *Conductors.* The normal mechanical tension in the conductors generally shall be the same in the crossing span and in the adjoining span on each side.

15. The conductors shall not be spliced in the crossing span nor in the adjoining span on either side.

Taps to conductors in the crossing span are generally objectionable, and should not be made unless necessary.

16. The ties or devices for supporting the conductors at the poles, or towers, shall be such as to hold the wires, under maximum load-

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* NOTE. This requirement does not apply to wires of the same phase or polarity between which there is no difference of potential.

ing, to the supporting structures, in case of shattered insulators, or wires broken or burned at an insulator, without allowing an amount of slip which would materially reduce the clearance specified in Paragraphs 9 and 10.

17. *Ground wires* when installed as protection against lightning, shall be thoroughly grounded at each of the crossing supports. In case of their installation on steel supporting structures, they may be clamped thereto. In case they are installed on wooden structures, the ground wire shall be grounded at each of the structures with a solid copper wire, with as few bends as possible, and no sharp bends, and not less than No. 4 B. & S. gage or equivalent copper section. The ground wire itself, in the crossing span and the adjacent spans, may be of the same material as the conductors, or a steel strand not less than 5/16 in. in diameter may be used, double galvanized, and having a breaking strength of not less than 4500 lb. and in general shall follow the minimum factors of safety, as provided for the rest of the crossing construction.

If cross-arms are grounded, the same ground wire may be used for grounding the lightning protection wire as in grounding cross-arm strips.

18. Where there is an upward stress at the point of conductor attachment, the attachment shall be of such type as to properly hold the conductor in place.

19. *Guys.* Wooden poles supporting the crossing span shall be side-guyed in both directions, if practicable, and be head-guyed away from the crossing span, and the next adjoining poles shall be head-guyed toward the crossing span. Braces may be used instead of guys.

20. *Strain insulators* shall be used in guys from wooden poles, except when the guys are through grounded to permanently damp earth.

The insulators shall be placed not less than 8 ft. from the ground. Strain insulators shall not be used in guying steel poles or structures.

21. *Clearing.* The space around the poles, or towers, shall be kept free from inflammable material, underbrush and grass.

22. *Signs.* In the case of railroad crossings, if required by the railroad company, warning signs of an approved design shall be placed on all poles and towers located on the railroad company's right of way.

23. *Grounding.* For voltages over 5000 volts, wooden cross-arms, if used, shall be provided with a grounded metallic plate on top of the arm, which shall be not less than 1/8 in. in thickness and which shall have a sectional area and conductivity not less than that of the line conductor. Metal pins shall be electrically connected to this ground. Metal plates and metal arms on wooden poles shall be grounded.

24. The electrical conductivity of the ground conductor shall be adjusted to the short-circuit current capacity of the system at the crossing and shall be not less than that of a No. 4 B. & S. gage copper wire.

25. *Temperature.* In the computation of stresses and clearances, and in erection, provision shall be made for a variation in tempera-

ture from − 20 deg. F. to + 120 deg. F. A suitable modification in the above temperature requirements shall be made for regions in which the above limits would not fairly represent the extreme range of temperature.

26. *Inspection.* If required by contract, all material and workmanship shall be subject to the inspection of the company crossed, provided that reasonable notice of the intention to make shop inspection shall be given by such company. Defective material shall be rejected and shall be removed and replaced with suitable material.

27. On the completion of the work, all false work, plant and rubbish incident to the construction shall be removed promptly and the site left unobstructed and clean.

28. *Drawings.* If required, by contract,.................... (......) complete sets of general and detail drawings shall be furnished for approval before any construction is commenced.

29. **Loads.** The conductors shall be considered as uniformly loaded throughout their length, with a load equal to the resultant of the dead load plus the weight of a layer of ice ½ in. in thickness and a wind pressure of 8.0 lb. per square foot on the ice-covered diameter, at a temperature of 0 deg. F.

30. The weight of ice shall be assumed as 57 lb. per cubic foot (0.033 lb. per cubic inch).

31. Insulators, pins and conductor attachments shall be designed to withstand the mechanical tension in the conductors under the maximum loadings with the designated factor of safety.

32. Sags should be such that the stress on the pin falls within the limits of Paragraph 31, unless methods be employed to prevent an undue slip in case of pin failure. (See Paragraphs 9, 10 and 16.)

33. The pole, or towers, shall be designed to withstand, with the designated factor of safety, the combined stresses from their own weight, the wind pressure on the pole, or tower, and the above wire loading on the crossing span and the next adjoining span on each side. The wind pressure on the poles, or towers, shall be assumed at 13 lb. per square foot on the projected area of solid or closed structures and one and one-half times the projected area of latticed structures.

34. The poles, or towers, shall also be designed to withstand the loads specified in Paragraph 33, combined with the unbalanced tension of:

2 broken wires for poles, or towers, carrying 5 wires or less.
3 broken wires for poles, or towers, carrying 6 to 10 wires.
4 broken wires for poles, or towers, carrying 11 or more wires.

35. Cross-arms shall be designed to withstand the loading specified in Paragraph 33, combined with the unbalanced tension of one wire broken at the pin farthest from the pole.

36. The poles, or towers, may be permitted a reasonable deflection under the specified loading, provided that such deflection does not reduce the clearance specified in Paragraph 10 more than 25 per cent. or produce stresses in excess of those specified in Paragraphs 69 to 73.

37. **Factors of Safety.** The ultimate unit stress divided by the allowable unit stress shall be not less than the following:

Wires and cables	2
Pins	2
Insulators, conductor attachments, guys	3
Wooden poles and cross-arms	6
Structural steel	3
Reinforced concrete poles and cross-arms	4
Foundations	2

NOTE. The use of treated wooden poles and cross-arms is recommended. The treatment of wooden poles and cross-arms should be by thorough impregnation with preservative by either closed or open-tank process. For poles, except in the case of yellow pine, the treatment need not extend higher than a point 2 ft. above the ground line.

38. *Insulators.* Insulators for line voltages of less than 9000 shall not flash over at four times the normal working voltage, under a precipitation of water of ⅕ in. per minute, at an inclination of 45 deg. to the axis of the insulator.

39. Each separate part of a built-up insulator, for line voltages over 9000, shall be subjected to the dry flash-over test of that part for 5 consecutive minutes.

40. Each assembled and cemented insulator shall be subjected to its dry flash-over test for 5 consecutive minutes.

The dry flash-over test shall be not less than:

Line voltage	Test voltage
Exceeding 9,000 but not exceeding 14,000	65,000
Exceeding 14,000 but not exceeding 27,000	100,000
Exceeding 27,000 but not exceeding 35,000	125,000
Exceeding 35,000 but not exceeding 47,000	150,000
Exceeding 47,000 but not exceeding 60,000	180,000
Exceeding 60,000	three times line voltage

Each insulator shall further be so designed that, with excessive potential, failure will first occur by flash-over and not by puncture.

41. Each assembled insulator shall be subjected to a wet flash-over test, under a precipitation of water of ⅕ in. per minute, at an inclination of 45 deg. to the axis of the insulator.

The wet flash-over test shall be not less than·

Line voltage	Test voltage
Exceeding 9,000 but not exceeding 14,000	40,000
Exceeding 14,000 but not exceeding 27,000	60,000
Exceeding 27,000 but not exceeding 35,000	80,000
Exceeding 35,000 but not exceeding 47,000	100,000
Exceeding 47,000 but not exceeding 60,000	120,000
Exceeding 60,000	twice the line voltage

42. Test voltages above 35,000 volts shall be determined by the A. I. E. E. Standard Spark-gap Method.

43. Test voltages below 35,000 volts shall be determined by transformer ratio.

44. **Material.** *Conductors.* The conductors shall be of copper, aluminum, or other non-corrodible material, except that in exceptionally long spans, where the required mechanical strength cannot be obtained with the above materials, galvanized or oper-covered steel strand may be used.

45. For voltages not exceeding 750 volts, solid or stranded conductors may be used up to and including 0000 in size; above 0000 in size, stranded conductors shall be used. For voltages exceeding 750 volts, and not exceeding 5000 volts, solid or stranded conductors may be used up to and including 00 in size; above 00 in size, conductors shall be stranded. For voltages exceeding 5000 volts, all conductors shall be stranded. Aluminum conductors for all voltages and sizes shall be stranded.

The minimum size of conductors shall be as follows:

No. 6 B. & S. gage copper for voltages not exceeding 5000 volts.
No. 4 B. & S. gage copper for voltages exceeding 5000 volts.
No. 1 B. & S. gage aluminum for all voltages.

46. *Insulators.* Insulators shall be of porcelain for voltages exceeding 5000 volts.

47. For pin type insulators, there shall be a bearing contact between the pin and the insulator pin hole up to the level of the top of the tie wire groove, the purpose being that the pin should directly take the strain imposed upon the insulator.

48. Strain insulators for guys shall have an ultimate strength of not less than twice that of the guy in which placed. Strain insulators shall be so constructed that the guy wires holding the insulator in position will interlock in case of the failure of the insulator.

For less than 5000 volts, strain insulators for guys shall not flash over at four times the maximum line voltage under a precipitation of water of ⅕ in. per minute, at an inclination of 45 deg. to the axis of the insulator. For voltages of more than 5000 volts, the strain insulator or series of strain insulators shall not fail at the line voltage under the above precipitation conditions.

49. *Pins.* For voltages of 5000 and over, insulator pins shall be of steel, wrought iron, malleable iron, or other approved metal or alloy, and shall be galvanized, or otherwise protected from corrosion. (See Paragraph 47.)

50. *Guys.* Guys shall be galvanized or copper-covered stranded steel cable not less than 5/16 in. in diameter, or galvanized rolled rods, neither to have an ultimate tensile strength of less than 4500 lb.

51. Guys to the ground shall connect to a galvanized anchor rod, extending at least 1 ft. above the ground level.

52. The detail of the anchorage shall be definitely shown upon the plans.

53. *Wooden Poles.* Wooden poles shall be of selected timber, reasonably straight, peeled, free from defects which would decrease their strength or durability, not less than 8 in. in diameter at the top, and meeting the requirements as specified in Paragraphs 19, 33, 34 and 37.

54. *Concrete.* All concrete and concrete material shall be in accordance with the requirements of the Report of the Joint Committee on Concrete and Reinforced Concrete.

NOTE. This may be found in the February, 1913, Proceedings of the American Society of Civil Engineers, Vol. LIX, No. 2, pp. 117–168.

55. **Structural Steel.** Structural steel shall be in accordance with the Manufacturer's Standard Specifications.

56. The design and workmanship shall be strictly in accordance with first-class practice.

57. The form of the frame shall be such that the stresses may be computed with reasonable accuracy, or the strength shall be determined by actual test.

58. The sections used shall permit inspection, cleaning and painting, and shall be free from pockets in which water or dirt can collect.

59. The length of a main compression member shall not exceed 180 times its least radius of gyration. The length of a secondary compression member shall not exceed 220 times its least radius of gyration.

60. The minimum thickness of metal in galvanized structures shall be ¼ in. for main members and ⅛ in. for secondary members. The minimum thickness of painted material shall be ¼ in.

61. **Protective Coatings.** All structural steel shall be thoroughly cleaned at the shop and be galvanized, or given one coat of approved paint.

62. *Painted Materials.* All contact surfaces shall be given one coat of paint before assembling.

All painted structural steel shall be given two field coats of an approved paint.

The surface of the metal shall be thoroughly cleaned of all dirt, grease, scale, etc., before painting, and no painting shall be done in freezing or rainy weather.

63. *Galvanized Material.* Galvanized material shall be in accordance with the Specification for Galvanizing Iron and Steel.

Bolt holes in galvanized material shall be made before galvanizing. Sherardizing for small parts is permissible.

64. **Foundations.** The foundations for steel poles and towers shall be designed to prevent overturning.

The weight of concrete shall be assumed as 140 lb. per cubic foot. In good ground, the weight of "earth" (calculated at 30 deg. from the vertical) shall be assumed as 100 lb. per cubic foot. In swampy ground, special measures shall be taken to prevent uplift or depression.

Concrete for foundation shall be well worked, very wet, and shall not be leaner than one part Portland cement, three parts clean, sharp sand, and six parts of broken stone, or one part Portland cement to six parts of good gravel, free from loam or clay.

65. The top of the concrete foundation, or casing, shall be not less than 6 in. above the surface of the ground, nor less than 1 ft. above high water, except that no foundation need be higher than the base of the railroad company's rail, or the top of the travelled roadway.

66. When located in swampy ground, wooden crossing and next adjoining poles shall be set in barrels of broken stone or gravel, or in broken stone or timber footings.

67. When located in the sides of banks, or when subject to washouts, foundations shall be given additional depth, or be protected by cribbing or riprap.

68. All foundations and pole settings shall be tamped in 6-in.

layers, while back-filling. It is desirable in back-filling that the earth be suitably moistened.

Working Unit Stresses. Obtained by dividing the ultimate breaking strength by the factors of safety given in Paragraph 37.

69. *Structural Steel*

Tension (net section)	18,000	lb. per sq. in.
Shear	14,000	lb. per sq. in.
Compression	$18{,}000 - 60\frac{l}{r}$	per sq. in.

70. *Rivets, Pins:*

Shear	10,000	lb. per sq. in.
Bearing	20,000	lb. per sq. in.
Bending	20,000	lb. per sq. in.

71. *Bolts:*

Shear	8,500	lb. per sq. in.
Bearing	17,000	lb. per sq. in.
Bending	17,000	lb. per sq. in.

72. *Wires and Cables:*

Copper, hard-drawn, solid, B. & S. gage 0000, 000, 00	25,000 lb. per sq. in.
Copper, hard-drawn, solid, B. & S. gage 0	27,500 lb. per sq. in.
Copper, hard-drawn, solid, B. & S. gage No. 1	27,500 lb. per sq. in.
Copper, hard-drawn, solid, B. & S. gage No. 2, 4, 6.	30,000 lb. per sq. in.
Copper, soft-drawn, solid	17,000 lb. per sq. in.
Copper, hard-drawn, stranded	30,000 lb. per sq. in.
Copper, soft-drawn, stranded	17,000 lb. per sq. in.
Aluminum, hard-drawn, stranded, B. & S. gage under 0000	12,000 lb. per sq. in.
Aluminum, hard-drawn, stranded, B. & S. gage 0000 and over	11,500 lb. per sq. in.

73. *Untreated Timber:*

	Lb. per sq. in.	$\left(1 - \frac{L}{60D}\right)$
Eastern white cedar	600	600
Chestnut	850	850
Washington cedar	850	850
Idaho cedar	850	850
Port Orford cedar	1150	1150
Long-leaf yellow pine	1000	1000
Short-leaf yellow pine	800	800
Douglas fir	900	900
White oak	950	950
Red cedar	700	700
Bald cypress (heartwood)	800	800
Redwood	650	650
Catalpa	500	500
Juniper	550	550

L = length in inches.
D = least side, or diameter, in inches.

Test for Galvanizing or Sherardizing

(A.E.R.E.A. Standard)

The coating should consist of a continuous coating of pure zinc, zinc-iron alloy or a combination of the two, the coating to be of uniform thickness and so applied that it adheres firmly to the iron or steel. The finished product should be smooth.

(a) Cleaning of Samples: The sample should be cleaned before testing, first with benzine or turpentine, using cotton waste (not with a brush), and then thoroughly rinsed in clean water and wiped dry with clean cotton waste.

(b) Test Solution: The standard solution of copper sulphate consists of commercial copper sulphate crystals dissolved in cold water about in the proportion of 36 parts by weight of crystals to 100 parts by weight of water. The solution must be neutralized by the addition of an excess of chemically pure cupric oxide (CuO), an excess of which is shown by the sediment of this reagent at the bottom of the container. The neutralized solution must be filtered before using, and the filtered solution must have a specific gravity of 1.186 at 18 deg. C. at the beginning of each test. This specific gravity is to be obtained by the addition of clean water if the gravity of the filtered solution is too high or by the addition of a filtered solution of a higher specific gravity if too low. The unfiltered neutralized stock solution should be replenished after each removal by the addition of more copper sulphate crystals and water. An excess of cupric oxide should always be kept in the unfiltered stock solution.

(c) Quantity of Solution: Wire samples should be tested in a glass jar of not less than 2 in. inside diameter filled to a depth of not less than 4 in. with the standard solution without the samples. Hardware samples should be tested in a glass or earthenware jar containing not less than ½ pint of standard solution for each sample. A new solution should be used for each series of four immersions.

(d) Samples: Not more than seven wires should be simultaneously immersed and not more than one sample other than wire should be immersed in the specified quantity of solution. Samples when immersed should not be grouped or twisted together.

(e) Method of Test: The samples prepared for test should be immersed in the specified quantity of standard solution, the temperature of which should be between 17 and 20 deg. C. throughout the test, in the following manner: First, immerse for 1 minute, wash and wipe dry; second, immerse for 1 minute, wash and wipe dry; third, immerse for 1 minute, wash and wipe dry; fourth, immerse for 1 minute, wash and wipe dry. The samples should be immediately washed in clean water having a temperature of 17 to 20 deg. C. and wiped dry after each immersion. In the case of sherardized material, the specimens must be vigorously brushed in running water after each dip. In testing wire, the No. 12 B.W.G. and smaller sizes should be required to stand three 1-minute and one ½-minute immersions. If after the test above described the samples show a bright metallic copper deposit, the lot represented by the samples should be rejected unless the deposit is on zinc or within 1 in. of the cut end. If only one wire in a group of seven simultaneously immersed should fail, or if there is reasonable doubt of the copper deposit, two check tests should be made upon these lots, and the report based upon the majority of the sets of tests. In case the article has a cut screw, the thread should be recut after galvanizing and shall stand at least one 1-minute immersion in the test solution. The rest of the article should withstand the specified four immersions. The threads of nuts should be cut after the nut has been galvanized, and the threads should not be required to stand the test.

Electric Wire and Cable Terminology, A.E.R.E.A. Standard

NOTE. Same as recommended by U.S Bureau of Standards, circular No. 37.

1. *Wire.* A slender rod or filament of drawn metal.

The definition restricts the term to what would ordinarily be understood by the term "solid wire." In the definition, the word "slender" is used in the sense that the length is great in comparison with the diameter. If a wire is covered with insulation, it is properly called an insulated wire; while primarily the term "wire" refers to the metal, nevertheless when the context shows that the wire is insulated the term "wire" will be understood to include the insulation.

2. *Conductor.* A wire or combination of wires not insulated from one another, suitable for carrying a single electric current.

The term "conductor" is not to include a combination of conductors insulated from one another, which would be suitable for carrying several different electric currents. Rolled conductors (such as bus bars) are, of course, conductors, but are not considered under the terminology here given.

3. *Stranded Conductor.* A conductor composed of a group of wires or any combination of groups of wires.

The wires in a stranded conductor are usually twisted or braided together.

4. *Cable.* (1) A stranded conductor (single-conductor cable); or (2) a combination of conductors insulated from one another (multiple-conductor cable).

The component conductors of the second kind of cable may be either solid or stranded, and this kind of cable may or may not have a common insulating covering. The first kind of cable is a single conductor, while the second kind is a group of several conductors. The term "cable" is applied by some manufacturers to a solid wire heavily insulated and lead covered; this usage arises from the manner of the insulation, but such a conductor is not included under this definition of "cable." The term "cable" is a general one and in practice it is usually applied only to the larger sizes. A small cable is called a "stranded wire" or a "cord," both of which are defined above. Cables may be bare or insulated, and the latter may be armored with lead or with steel wires or bands.

5. *Strand.* One of the wires or groups of wires of any stranded conductor.

6. *Stranded Wire.* A group of small wires, used as a single wire.

A wire has been defined as a slender rod or filament of drawn metal. If such a filament is subdivided into several smaller filaments or strands and is used as a single wire, it is called "stranded wire." There is no sharp dividing line of size between a "stranded wire" and a "cable." If used as a wire, for example, in winding inductance coils or magnets, it is called a stranded wire and not a cable. If it is substantially insulated, it is called a "cord," defined below.

7. *Cord.* A small cable, very flexible and substantially insulated to withstand wear.

There is no sharp dividing line in respect to size between a "cord" and a "cable," and likewise no sharp dividing line in respect to the character of insulation between a "cord" and a "stranded wire." Usually the insulation of a cord contains rubber.

8. *Concentric Strand.* A strand composed of a central core surrounded by one or more layers of helically laid wires or groups of wires.

9. *Concentric Lay Cable.* A single conductor cable composed of a central core surrounded by one or more layers of helically laid wires.

10. *Rope Lay Cable.* A single conductor cable composed of a central core surrounded by one or more layers of helically laid groups of wires.

This kind of cable differs from the preceding in that the main strands are themselves stranded.

11. *N-Conductor Cable.* A combination of N conductors insulated from one another.

It is not intended that the name as here given be actually used. One would instead speak of a "3-conductor cable," a "12-conductor cable," etc. In referring to the general case, one may speak of a "multiple-conductor cable" (as in definition No. 4 above).

12. *N-Conductor Concentric Cable.* A cable composed of an insulated central conducting core with (N−1) tubular stranded conductors laid over it concentrically and separated by layers of insulation.

Usually only 2-conductor or 3-conductor. Such conductors are used in carrying alternating currents. The remark on the expression "N-conductor" given for the preceding definition applies here also.

13. *Duplex Cable.* Two insulated single-conductor cables twisted together.

They may or may not have a common insulating covering.

14. *Twin Cable.* Two insulated single-conductor cables laid parallel, having a common covering.

15. *Triplex Cable.* Three insulated single-conductor cables twisted together.

They may or may not have a common insulating covering.

16. *Twisted Pair.* Two small insulated conductors twisted together, without a common covering.

The two conductors of a "twisted pair" are usually substantially insulated, so that the combination is a special case of a "cord."

17. *Twin Wire.* Two small insulated conductors laid parallel, having a common covering.

Rubber Insulated Wire and Cable for Power Distribution
(A.E.R.E.A. Standard)

Grades. Two grades of rubber insulation for distribution wires and cables are designated by the A.E.R.E.A. as "Grade A Rubber Insulation" and "Grade B Rubber Insulation." Grade A is a high-grade insulation for use on circuits of working pressure not exceeding 15,000 volts. Grade B is for use where a cheaper insulation is desired and should not be used on circuits of working pressure in excess of 7000 volts.

Conductor Size and Stranding. The combined area of the wires when laid out straight and measured at right angles to their axes should not be less than the specified gage or circular mils. The stranding should be concentric and in accordance with the following table:

Range of sizes	Minimum number of wires in conductor	
	Standard stranding	Flexible stranding
2,000,000–1,600,000 cir. mils	127	169
1,500,000–1,100,000 cir. mils	91	127
1,000,000– 550,000 cir. mils	61	91
500,000– 250,000 cir. mils	37	61
No. 0000–No. 1 A.W.G.	19	37
2–8	7	19
Smaller sizes	1	7

Conductor Material. The conductor should be of annealed copper, conforming to the standard specifications of the American

Society for Testing Materials. It should be provided with a heavy uniform coating of commercially pure tin, without projections. The tinning may be tested as follows: Samples of the wire should be thoroughly cleaned with alcohol and immersed in hydrochloric acid of specific gravity 1.088 at 15.5 deg. C. (60 deg. F.) for 1 minute. They should then be rinsed in pure water and immersed in an aqueous solution of sodium sulphide of specific gravity 1.142 for 30 seconds and again washed. This operation should be repeated three times. At the end of the fourth immersion in sodium sulphide the wire should show no sign of blackening. The sodium sulphide solution should contain an excess of sulphur and should have sufficient strength to thoroughly blacken a piece of untinned copper wire in 5 seconds.

Separator. The separator may consist of soft cotton yarn (which may be braided), or of paper or muslin tape. The separator should allow the insulation sufficient contact with the conductor to prevent the conductor sliding in the insulation.

Insulation Thickness. The thickness of insulation for potentials up to 7000 volts should be the minimum allowed by the National Board of Fire Underwriters, as summarized in the following table.

A.W.G. (B. & S.)	Working voltage					
	0–600	1500	2500	3500	5000	7000
	Thickness of insulation, 64ths of one inch					
14	3	4	6	8	12	16
12	3	4	6	8	12	16
10	3	4	6	8	12	16
8	3	4	6	8	12	16
6	4	5	6	8	12	16
4	4	5	6	8	12	16
2	4	5	6	8	12	16
1	5	6	7	8	12	16
0	5	6	7	8	12	16
00	5	6	7	8	12	16
000	5	6	7	8	12	16
0000	5	6	7	8	12	16
Cir. mils						
225,000	6	7	8	9	12	16
300,000	6	7	8	9	12	16
400,000	6	7	8	9	12	10
500,000	6	7	8	9	12	16
600,000	7	8	9	10	12	16
700,000	7	8	9	10	12	16
800,000	7	8	9	10	12	16
900,000	7	8	9	10	12	16
1,000,000	7	8	9	10	12	16
1,250,000	8	9	10	11	14	18
1,500,000	8	9	10	11	14	18
1,750,000	8	9	10	11	14	18
2,000,000	8	9	10	11	14	18

(For higher voltages, the thickness of insulation will depend upon the conditions of service.)

Insulation Repairs and Joints. If exigencies of manufacture require repairs or joints in the insulation, the work should be done in such a way as to leave the repaired part or the joint and all parts affected by it as strong and durable electrically as the remainder of the insulation. The repairs or joints should be properly vulcanized in a mold of approximately the same diameter as the remainder of the insulation.

Insulation rubber compound should be thoroughly and properly vulcanized. The vulcanized insulation should be homogeneous in character, tough and elastic and should be concentric about the conductors and fit tightly thereto. All laps or seams in the insulation should be as strong mechanically and electrically as the rest of the insulation.

"*Grade A Rubber Insulation.*" (1) A 30 per cent. fine Para or smoked first latex Hevea rubber compound with mineral base should be furnished. It should contain only the following ingredients: Rubber, sulphur, inorganic mineral matter, refined solid paraffin or ceresine.

(2) It should not contain either red lead or carbon.

(3) The vulcanized compound should conform to the following requirements, when tested by the procedure of the Joint Rubber Insulation Committee (see Proc. A.I.E.E., Jan., 1914).

(a) Results to be expressed as percentages by weight of the whole sample.

	Maximum	Minimum
Rubber	33.0	30
Waxy hydrocarbons	4.0	
Free sulphur	0.7	

(b) Results to be taken between the limits given in proportion to the percentage by weight of rubber found:

Limits allowed for 30 per cent. rubber compound:

Saponifiable acetone extract	1.35	0.55
Unsaponifiable resins	0.45	
Chloroform extract	0.90	
Alcoholic potash extract	0.55	
Specific gravity		1.75

Limits allowed for 33 per cent. rubber compound:

Saponifiable acetone extract	1.50	0.60
Unsaponifiable resins	0.50	
Chloroform extract	1.00	
Alcoholic potash extract	0.60	
Specific gravity		1.67

(4) The acetone solution should not fluoresce.

(5) The acetone extract (60 c.c.) should not be darker than a light straw color.

(6) Hydrocarbons should be solid, waxy and not darker than a light brown.

(7) Chloroform extract (60 c.c.) should not be darker than a straw color.

(8) Failure to meet any requirement of this specification should be sufficient cause for rejection.

(9) Contamination of the compound, such as by the use of impregnated tapes, should not excuse a contractor from conforming to this specification.

"*Grade B Rubber Insulation.*" The vulcanized rubber compound should show, when analyzed by the procedure hereinafter specified, not less than 27 per cent. of rubber gum.

Five chemical tests should be made of the vulcanized rubber compound as follows: Acetone extract, alcoholic potash extract, chloroform extract, ash, total sulphur.

The sum total of the results of these five tests should not exceed 73 per cent. by weight of the total compound.

The ash test should be supplemented by tests to determine the quantity of substances other than vulcanized rubber which are combustible but not soluble in acetone, alcoholic potash, or chloroform, and any such substance, if any, should be counted as ash.

The tests should be made in accordance with the Underwriters Laboratories' specification.

Contamination of the compound, such as by the use of impregnated tapes, should not excuse a contractor from conforming to this specification.

Tensile Strength and Elongation of Rubber Insulation. A sample which may be of entire, segmental, or approximately rectangular cross-section, should be cut from the insulated conductor by means of a sharp knife. The sample should be bent in every direction to magnify and reveal any surface incision or imperfection which may exist. A portion of the sample without such defects and having a free length of not less than 2 in. should then be stretched at the rate of 12 in. per minute until it breaks; another sample should be stretched to three times its length and immediately released. Marks should be placed on the insulation before its removal from the conductor. The compound should conform to the following limits:

Property	Thickness			
	12/64 inches or less		Over 12/64 inches	
	Maximum	Minimum	Maximum	Minimum
Tensile strength, lb. per sq. in. (each sample)	....	1000	....	1000
Elongation in 2-in. length at break (times original length)	....	5	....	4
Elongation 5 seconds after release when stretched at the rate of 12 in. per minute to three times its length.	20%	....	20%	....

TEST VOLTAGES, KILOVOLTS FOR 5-MINUTE TESTS

Use 100 per cent. of the following voltages for Grade A
Use 80 per cent. of the following voltages for Grade B

Size of conductors	Thickness of insulation, 64ths. of one inch																
	2	3	4	5	6	7	8	10	12	14	16	18	20	22	24	26	28
2,000,000 cir. mils	....	....	....	....	....	....	5.0	10.5	19	22	24	26	28	30	31	33	34
1,750,000 cir. mils	....	....	....	....	....	....	6.5	11.5	19	22	24	26	28	30	31	33	34
1,500,000 cir. mils	....	....	....	....	....	....	7.0	12.0	19	22	24	26	28	30	31	33	34
1,250,000 cir. mils	....	....	....	....	....	....	7.5	12.5	19	22	24	26	28	30	31	33	34
1,000,000 cir. mils	....	....	....	....	....	5.5	8.0	13.0	19	22	24	26	28	30	31	33	34
750,000 cir. mils	....	....	....	....	....	6.5	9.0	14.0	19	22	24	26	28	30	31	33	34
500,000 cir. mils	....	....	....	2.5	5.0	7.5	10.0	14.5	19	22	24	26	28	30	31	33	34
250,000 cir. mils	....	....	....	4.0	6.5	9.0	11.0	15.5	19	22	24	26	28	30	31	33	34
0000 A.W.G.	....	....	....	4.5	7.0	9.0	11.5	15.5	18	21	23	25	27	28	30	31	32
000 A.W.G.	....	....	....	5.0	7.5	9.5	11.5	15.5	18	21	23	25	27	28	30	31	32
00 A.W.G.	....	....	....	5.0	7.5	9.5	11.5	15.5	18	21	23	25	27	28	30	31	32
0 A.W.G.	....	....	....	5.5	8.0	10.0	12.0	15.5	18	21	23	25	27	28	30	31	32
1 A.W.G.	....	....	4.0	6.0	8.0	10.0	12.0	15.5	18	21	23	25	27	28	30	31	32
2 A.W.G.	....	....	4.0	6.0	8.0	10.0	12.0	15.0	17	19	22	24	25	26	28	29	30
4 A.W.G.	....	....	4.5	6.5	8.5	10.0	11.5	14.5	17	19	22	24	25	26	28	29	30
6 A.W.G.	....	....	5.0	6.5	8.5	10.0	11.5	14.0	16	18	20	22	23	25	26	28	29
8 A.W.G.	....	3.0	5.0	7.0	8.0	9.5	11.0	13.0	....	....	....	....	....	....	....	....	....
10 A.W.G.	....	3.0	5.0	6.5	8.0	8.5	10.0	12.0	....	....	....	....	....	....	....	....	....
12 A.W.G.	....	2.5	5.0	6.0	7.5	8.5	9.5	11.5	....	....	....	....	....	....	....	....	....
14 A.W.G.	....	2.5	5.0	6.0	7.0	8.0	9.0	11.0	....	....	....	....	....	....	....	....	....
16 A.W.G.	1.0	2.5	4.5	5.5	6.5	7.5	8.5	10.5	....	....	....	....	....	....	....	....	....
18 A.W.G.	1.0	2.5	4.5	5.5	6.5	7.5	8.5	10.5	....	....	....	....	....	....	....	....	....

(For intermediate sizes use the voltages corresponding to the next larger size, having the same thickness of insulation.)
(For a 30-minute test use 80 per cent. of value for 5-minute test.)

MEGOHM-MILES AT 60 DEG. F., BASED UPON THE CONSTANT 4000 1-MINUTE ELECTRIFICATION

Minimum shall be 100 per cent. of following for Grade A and 80 per cent. for Grade B

Size of conductors	Thickness of insulation, 64ths. of one inch																
	2	3	4	5	6	7	8	10	12	14	16	18	20	22	24	26	28
2,000,000 cir. mils..							200	275	325	425							
1,750,000 cir. mils..							275	300	375	450							
1,500,000 cir. mils..							300	325	400	475							
1,250,000 cir. mils..							325	375	425	500	575						
1,000,000 cir. mils..						300	325	400	475	550	625						
750,000 cir. mils..						325	400	475	525	625	700	775					
500,000 cir. mils..				300	375	400	475	575	675	750	850	900					
350,000 cir. mils..				350	425	475	525	675	775	850	950	1050	1125				
250,000 cir. mils..				400	475	575	625	725	875	1000	1100	1200	1275				
0000 A.W.G..				450	550	600	650	800	950	1050	1150	1250	1350	1450			
000 A.W.G..				500	600	650	750	850	1000	1150	1250	1350	1450	1550			
00 A.W.G..				550	650	750	850	950	1050	1250	1350	1500	1600	1700	1800		
0 A.W.G..				600	700	800	950	1050	1200	1350	1500	1600	1700	1800	1900	2000	
1 A.W.G..			600	650	750	850	1000	1150	1350	1450	1600	1750	1850	1950	2050	2150	2250
2 A.W.G..			650	750	850	950	1050	1250	1450	1600	1700	1850	1950	2100	2200	2300	2400
4 A.W.G..			750	850	1000	1150	1250	1450	1650	1850	2000	2150	2250	2400	2500	2600	2700
6 A.W.G..			850	1050	1200	1350	1450	1750	1950	2100	2300	2450	2550	2700	2800	2900	3000
8 A.W.G..		850	1050	1250	1450	1650	1750	2050	2200	2400	2600	2750	2900	3050	3150	3250	3350
10 A.W.G..		1150	1350	1600	1800	2000	2150	2400	2650	2900	3100	3250	3400	3550	3700	3800	3900
12 A.W.G..		1350	1600	1850	2020	2250	2400	2750	3000	3250	3400	3600	3750	3900	4050	4150	4300
14 A.W.G..		1550	1850	2150	2350	2550	2650	3050	3350	3550	3800	3950	4100	4300	4400	4550	4650
16 A.W.G..	1400	1800	2150	2400	2650	2850	3050	3400	3650	3950	4150	4350	4500	4660	4650	4900	5050
18 A.W.G..	1600	2050	2450	2800	3000	3200	3400	3750	4050	4300	4500	4700	4900	5000	5150	5300	5400

Electrical Tests. Each length of conductor insulated with the compound should be tested for dielectric strength and insulation resistance before the application of any outer covering other than tape or braid, after at least 12 consecutive hours' submersion in water and while still submersed.

DIELECTRIC STRENGTH. An alternating-current voltage of not less than twenty-five nor more than one hundred cycles and approximately as closely as possible to a sine wave should be applied between each conductor and the water for a period of 5 minutes. For a 30-minute test, 80 per cent. of the specified voltage should be used. Lead sheathed cables after being finished should have the test voltage applied between their conductors and also between all of the conductors and the sheath. The voltage to be applied should be in accordance with the table on page 660. The initially applied voltage must not be greater than the working voltage, and the rate of increase should not be over 100 per cent. in 10 seconds. The conductor must not show any weakening of its insulation or any other injury under this test, which is to be made before the test for insulation resistance.

INSULATION RESISTANCE. The insulation resistance should be measured after the high voltage test and following a 1-minute electrification with a continuous e.m.f. of not less than 100 nor more than 500 volts, and the results corrected to the standard temperature at 15.5 deg. C. (60 deg. F.). All tests for insulation resistance should be made at a temperature within 10 deg. C. (18 deg. F.) of this standard temperature. The insulation resistance of each conductor of multiple conductor cables should be the insulation resistance measured between each conductor and all the other conductors connected to the sheath or water. The insulation resistance should be not less than given in the table on page 661.

The insulation resistance at any given temperature should be reduced to that at 15.5 deg. C. (60 deg. F.) by dividing by the coefficient in the following table corresponding to that temperature for Grade A and Grade B insulation:

Temperature, deg. C.	Coefficient should be not greater than	Temperature, deg. C.	Coefficient should be not less than
7	1.53	16	0.98
8	1.45	17	0.93
9	1.37	18	0.89
10	1.30	19	0.85
11	1.23	20	0.81
12	1.17	21	0.77
13	1.12	22	0.73
14	1.07	23	0.70
15	1.02	24	0.67
15.5	1.00	25	0.64

Temperature, deg. F.	Coefficient should be not greater than	Temperature, deg. F.	Coefficient should be not less than
46	1.44	60	1.000
47	1.41	61	0.974
48	1.37	62	0.949
49	1.34	63	0.925
50	1.30	64	0.901
51	1.27	65	0.878
52	1.24	66	0.855
53	1.20	67	0.833
54	1.17	68	0.812
55	1.14	69	0.791
56	1.11	70	0.771
57	1.09	71	0.751
58	1.06	72	0.732
59	1.03	73	0.713
60	1.00	74	0.695
....	....	75	0.677

Weatherproof Braid

Weatherproof braid should consist of the required number of fine, smooth, closely woven braids, all of which must be thoroughly saturated with a dense waterproof compound having the properties hereinafter specified. The impregnated braids should be uniformly covered with a continuous layer of suitable weatherproof compound which should adhere firmly to the braids. The outer surface should be thoroughly slicked down.

Tape. The tape should be of cotton thoroughly saturated with a waterproof rubber compound and of proper weight and width.

Weatherproof Compound. The weatherproof compound should be such as to have no injurious action upon the insulation of the braid and it should be insoluble in water; it should be sufficiently elastic between the temperature of 4.5 deg. C. (40 deg. F.) and 32 deg. C. (90 deg. F.) so that the completed wire can be bent to a radius of ten times its outside diameter without showing cracks in the finished surface of the wire or squeezing out of the weatherproof compound. The weatherproof compound should be of such nature that it will not crack when the finished wire is subjected to a temperature of −23.3 deg. C. (−10 deg. F.), and that it will meet the requirements when the finished wire is subjected to the following melting test.

Melting Test for Weatherproof Compound. Short samples of the finished conductor should be placed on a piece of clean white paper in an oven and should be subjected to a temperature of 52 deg. C. (125 deg. F.) for ½ hour. The compound should not become sufficiently fluid to form a ridge upon the paper perceptible to the fingers, or, in case the compound should be absorbed by the paper, to show a greasy or oily spot upon the paper, nor should the compound show a tendency to flow toward the bottom of the conductor, thus exposing the cotton fiber of the braid at the top.

Application of Braid and Tape. If the conductor is to be finished with a braid, all conductors smaller than No. 8 A.W.G. should be double braided, No. 8 and larger to be double or single braided as required. The outside braids should be not less than 1/32 in. thick and the inside braid not less than 1/64 in. thick. Single braid should be not less than 1/32 in. thick. When multiple conductor cables are specified, the rubber insulation on each conductor should be covered with a layer of tape overlapping not less than one-quarter of its width. In the case of two conductor cables the separate conductors thus finished should be laid side by side and an outer covering of single braid not less than 1/32 in. thick should be then applied. In the case of three or more conductors the taped conductors should be twisted together with a suitable lay of at least one complete twist in 24 in., the interstices being filled with sufficient jute to make the core of circular cross-section. Over this core should then be applied a tape with an overlap of at least 1/8 in. and the outer covering of braid not less than 1/32 in. should then be applied.

Lead Cable Sheath

Composition and Thickness of Lead Cable Sheath. If the wire or cable is to be furnished with a lead sheath instead of an outer covering of braid, as provided in the preceding paragraph, there should be tightly formed about the core a lead sheath of uniform thickness not less than that indicated in the following table:

Diameter of core in mils	Thickness of sheath
Under 2000	1/8 in.
2000–2699	9/64 in.
2700 and over	5/32 in.

A sheath having an internal diameter of less than 2 in. should consist of commercially pure lead; a sheath having an internal diameter of 2 in. or more should consist of an alloy containing not less than 98 per cent. of commercially pure lead and not less than 1 per cent. of commercially pure tin.

Cable Armor

Protection Under Armor. Rubber insulated cable covered with tape, braid, or other suitable protection, or the lead sheath should be run through a hot asphalt compound, served with a layer of jute yarn, run through hot asphalt again, and then laid with galvanized wire armor.

Size of Armor Wire. The proper size of armor wire will depend upon the conditions of service; the latitude allowed in the following table represents the difference arising from such difference in service conditions. The armor wire should be the minimum size.

Diameter of cable under jute bedding, inches	Armor wire, U. S. (steel) W.G.	Jute bedding under armor measured in finished cable
0.00–0.50	14–13	1/16 in. minimum
0.44–0.69	12	1/16 in. minimum
0.63–1.00	10	1/16 in. minimum
0.88–1.50	8	1/16 in. minimum
1.25–2.00	6	1/16 in. minimum
1.30–larger	4	1/16 in. minimum

Lay of Armor. The armor should be applied closely without appreciable space between adjacent wires. The lay should be from eight to twelve times the pitch diameter. Successive layers of jute or jute and armor should be laid in opposite directions. The direction of lay is the lateral direction in which the wires run over the top of the cable as they recede from an observer looking along the axis of the cable.

Finish of Armored Cable. If an outer covering is required, the armored cable should be run through hot asphalt compound, served with a layer of the best three-ply 14-lb. hard twisted jute yarn in a close short lay, run through hot asphalt compound, then served with a second layer of three-ply 14-lb. jute yarn, run through hot asphalt compound and finally run through some material to prevent sticking.

Material of Armor Wire. All armor wire should consist of galvanized mild steel wire of uniform diameter, free from all cracks, splits, or other flaws; it should be of such softness that it will easily take a permanent set and give great pliability to the cable, permitting it to be coiled evenly and smoothly and showing no tendency to rise or spring in the flakes.

Tensile Strength of Armor Wire. Armor wire should have a tensile strength of not less than 60,000 lb. per square inch of cross-section and an elongation of not less than 10 per cent. in 10 in.

Flexibility of Armor Wire. The armor wire should admit of bending around a spindle of ten times the diameter of the wire and back again without developing cracks of the galvanizing which are visible to the naked eye.

Galvanizing of Armor Wire. (For tests, see page 653, Test for Galvanizing or Sherardizing).

Steel Tape Armor. If the cable is to be armored with steel tape the core covered with tape braid or other suitable protection should be run through a bath of hot asphalt compound, served with a layer of 14-lb. jute yarn, spun on with a close short lay, run through hot asphalt compound, armored with a steel tape; armored with second steel tape; run through hot asphalt compound, served with a layer of 100-lb. jute yarn with a close short lay, run through hot asphalt compound and finished by running through some material to prevent sticking. The layers of jute should be applied in the reverse directions. The space between adjacent turns of steel tape should not exceed one-tenth the width of the steel tape.

Thickness of Armor and Jute under Armor. The tape and jute under armor, after armoring, should conform to the following table:

Cable diameter before armoring, inches	Maximum width steel tape, inches	Minimum thickness each tape, inches	Minimum thickness under armor, inches
0.45	0.50	0.02	0.06
0.46–0.75	0.75	0.02	0.06
0.76–1.00	1.00	0.03	0.07
1.01–1.40	1.25	0.03	0.07
1.41–1.70	1.50	0.04	0.08
1.71–2.00	1.75	0.04	0.08
2.01–over	2.00	0.05	0.09

Galvanizing of Armor Tape. (For tests, see page 653, Test for Galvanizing or Sherardizing).

Single Conductor, Paper Insulated, Lead Covered Cable for 1200 Volts. The cable is composed of a single conductor, covered with paper tape to the required thickness. The paper, soaked in a suitable insulating compound, is covered with a lead sheath of the required thickness. The completed cable and the material of which it is made should conform to the requirements of the following.

Conductor. The conductor should consist of annealed copper wires, free from splints, flaws, or other defects, concentrically stranded together in reverse spiral layers, and having an aggregate cross-sectional area when measured at right angles to the axes of the individual wires at least equal to the area of the specified size, and in accordance with the following table:

Size of conductor	No. of wires
0.162 in.–0.204 in. diameter	1
0.229 in.–0.258 in. diameter	7
0.289 in.–0.460 in. diameter	19
300,000–500,000 cir. mils	37
600,000–1,000,000 cir. mils	61
1,100,000–1,500,000 cir. mils	91
1,600,000–and larger cir. mils	127

Intermediate sizes take the stranding of the next larger listed size. Each of the individual wires should have a resistivity of not more than 888.55 ohms (mile, pound), at 20 deg. C.

Insulation. The highest grade of pure manila rope paper tape should be applied helically and evenly to the conductor until the required thickness of paper is obtained. All moisture should be expelled from the paper by baking in suitable ovens; it should then be thoroughly saturated with the insulating compound of the required kind and quality. The paper tape must be applied to the conductor in such a manner, and the insulating compound must be of such a nature, that the cable will be capable of being bent to a radius of 12 in. when wound on reels and taken therefrom and put into place, at any temperature between 0 and 100 deg. F., without damage to the insulation or sheath. The insulating compound should contain no substance which will subject the paper or conductor to deterioration, and it should be of such composition as to maintain the insulation in a soft, plastic state at all seasons of the year.

Sheath. A sheath of uniform thickness, not less than ⅛ in. for cable under 1½ in. core diameter, and not less than 9/64 in. for cable with core diameter 1½ in. and larger, should be tightly formed about the core. A sheath having an internal diameter less than 1½ in. should consist of commercially pure lead. A sheath having an internal diameter of 1½ in. or more should consist of an alloy containing not less than 98 per cent. of commercially pure lead and not less than 1 per cent. of commercially pure tin.

Electrical Test. Each length of cable should be given the following dielectric strength and insulation resistance tests when mechanical operations of its construction are completed.

HIGH VOLTAGE TEST. An alternating current of 5000 volts should be applied between the conductor and the lead sheath for a period of 5 minutes. The cable must not show any weakening of its insulation or any other injury under this test, which is to be made before the test for insulation resistance. The frequency of the test voltage should not exceed 100 cycles per second and should approximate as closely as possible to a sine wave. The initially applied voltage should not be greater than the working voltage, and the rate of increase should not be over 100 per cent. in 10 seconds.

INSULATION RESISTANCE. Immediately after the dielectric test, a test should be made for insulation resistance. The measurement should be taken after 1 minute electrification, using an e.m.f. of not less than 100 volts, and should be not less than 50 megohms per mile at 60 deg. F.

High Voltage, Three Conductor, Paper Insulated, Lead Covered Cable. The cable should be composed of three copper conductors, each covered with paper tape to the required thickness, and then twisted together with a suitable lay. The interstices should be rounded out with jute and the whole wrapped with a paper belt to the required thickness. The paper, soaked in a suitable insulating compound, should be covered with a lead sheath of the required thickness. The completed cable, and the materials of which it is made, should conform to the following.

Conductors. Each conductor should consist of annealed copper wire, free from splints, flaws, or other defects, concentrically stranded together in reverse spiral layers, and having an aggregate cross-sectional area when measured at right angles to the axes of the individual wires at least equal to the area of the specified size and in accordance with the following table:

Size of conductor	No. of wires
0.162 in.-0.204 in. diameter	1
0.229 in.-0.258 in. diameter	7
0.289 in.-0.460 in. diameter	19

Each of the individual wires should have a resistivity of not more than 888.55 ohms (mile, pound), at 20 deg. C.

Insulation. The highest grade of pure manila rope paper tape should be applied helically and evenly to each of the conductors until the required thickness of paper is obtained. The conductors should then be twisted together, with a suitable lay of at least one complete twist in each 24 in. of length of cable. The interstices of the core so formed should be filled in with jute laterals, of the proper dimensions to form a true cylinder. The paper tape should then be applied helically and evenly over the core until the required thickness is obtained.

All moisture should be expelled from the paper and jute by baking in suitable ovens; they should then be thoroughly saturated with the insulating compound. The paper tape should be applied the conductors and the core in such a manner, and the insulating compound should be of such a nature, that the cable will be capable of being bent to a radius of 18 in. when wound on reels and taken therefrom and put into place, at any temperature between 0 and 100 deg. F., without damage to the insulation or sheath. The insulating compound should contain no substance which will subject the paper, jute or conductors to deterioration, and it should be of such composition as to maintain the insulation in a soft, plastic state at all seasons of the year.

Sheath. A sheath of uniform thickness, not less than that indicated in the following table, should be tightly formed about the core:

Diameter of core in mils	Thickness of sheath
Under 2000	1/8 in.
2000–2699	9/64 in.
2700 and over	5/32 in.

A sheath having an internal diameter less than 2 in. should consist of commercially pure lead. A sheath having an internal diameter of 2 in. or more should consist of an alloy containing not less than 98 per cent. of commercially pure lead, and not less than 1 per cent. of commercially pure tin.

Electrical Test. Each length of cable should be given the following dielectric strength and insulation resistance tests when mechanical operations of its construction are completed.

DIELECTRIC STRENGTH. An alternating-current voltage should be applied between each conductor and all the others connected to the lead sheath, for a period of at least 5 minutes. The voltage to be applied should be that corresponding to the combined thickness of the conductor and belt insulation in accordance with the following table:

Voltage	Thickness of insulation
5,000	9/64 in.
6,250	5/32 in.
7,500	3/16 in.
10,000	7/32 in.
12,500	1/4 in.
15,000	9/32 in.
20,000	5/16 in.
25,000	11/32 in.
30,000	3/8 in.
35,000	13/32 in.
40,000	7/16 in.
45,000	15/32 in.
50,000	1/2 in.
60,000	9/16 in.

The cable should not show any weakening of its insulation or any other injury under this test, which is to be made before the test for insulation resistance. The frequency of the test voltage should not exceed 100 cycles per second, and should approximate as closely as possible to a sine wave. The initially applied voltage should not be greater than the working voltage, and the rate of increase should not be over 100 per cent. in 10 seconds.

INSULATION RESISTANCE. Immediately after the dielectric test, a test should be made for insulation resistance, each conductor being measured against all the others connected to the lead sheath. The measurement should be taken after 1 minute electrification, using an e.m.f. of not less than 100 volts, and should be not less than 50 megohms per mile at 60 deg.

Tile Duct Conduit System

Tile Duct. (Fig. 38.) Each piece of tile duct should be of thoroughly vitrified and glazed tile, whole, sound, straight from end to end, with smooth interior surface, free from blisters, sharp corners and obstructions. The bore should be not less than the nominal diameter ordered, and should be symmetrical with, and the ends should be cut off square with, the longitudinal axis of the duct. The wall of the duct should be not less than 5/8 in. thick at the thinnest place, but the duct should average 5/8 in. thick. The

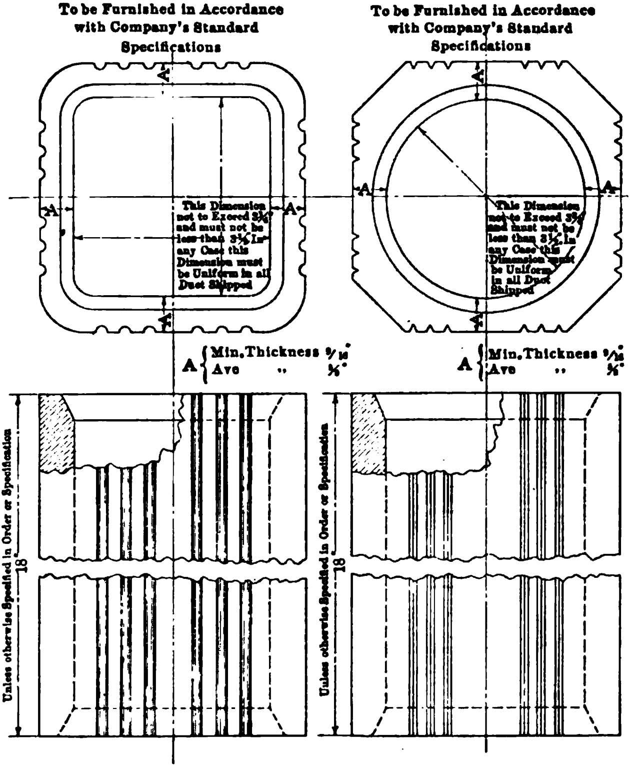
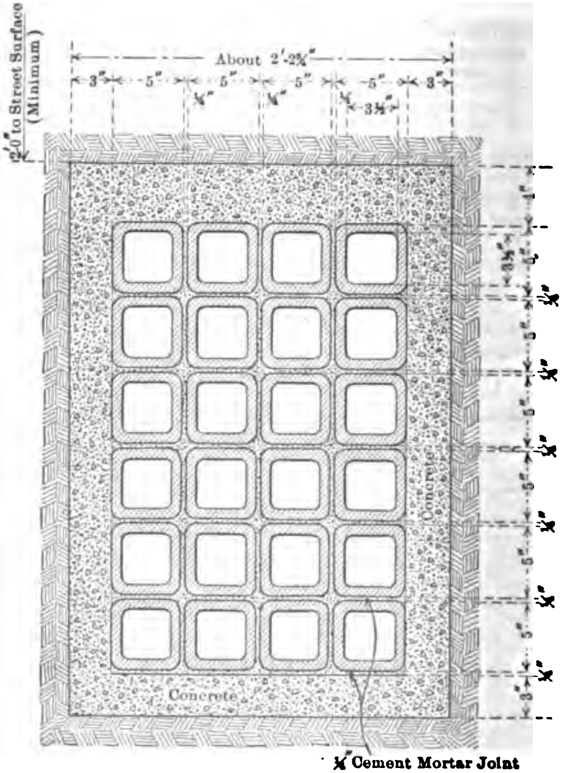

To be Furnished in Accordance with Company's Standard Specifications
To be Furnished in Accordance with Company's Standard Specifications
A
A
A
A
This Dimension not to Exceed 3⅝" and must not be less than 3⅛" In any Case this Dimension must be Uniform in all Duct Shipped
A
A
A
A
This Dimension not to Exceed 3⅝" and must not be less than 3⅛" In any Case this Dimension must be Uniform in all Duct Shipped
A { Min. Thickness 5/16" Ave " 5/8"
A { Min. Thickness 5/16" Ave " 5/8"
Unless otherwise Specified in Order or Specification 18"
Unless otherwise Specified in Order or Specification 18"

FIG. 38.—Tile duct, square and round.

inner edges of the ends of each piece of duct should be chamfered off so that sharp edges will not be encountered when cable is drawn in. The completed duct should have the necessary mechanical strength and toughness to prevent chipping at the ends, and breakage in ordinary handling. The outer surface of all duct should be scored in such manner as to give cement a hold on the surface of the duct.

Construction of Conduit. (Fig. 39.) A bed of concrete to the depth of not less than 3 and preferably 4 in. should be put in the bottom of the trench and the surface brought to grade. The duct should be laid like brickwork in cement mortar in such a manner as to break joints both horizontally and vertically. Care should be taken in selecting cement for the mortar used in this work, on account of the possi-



¼" Cement Mortar Joint

FIG. 39.—Typical conduit construction.

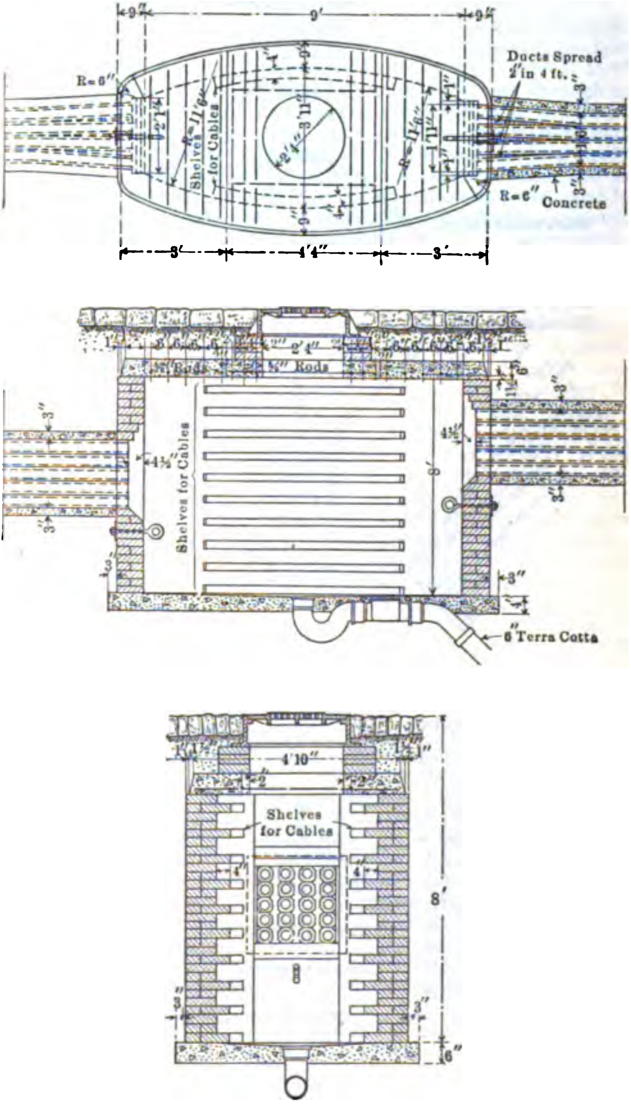


Fig. 40.—Typical two-way manhole.

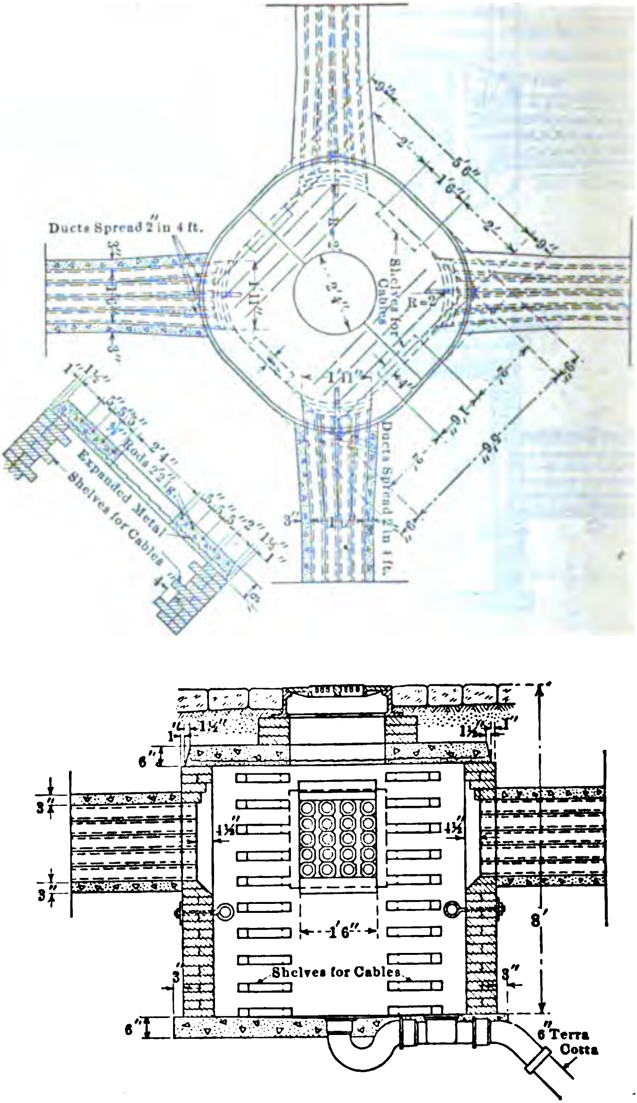


FIG. 41.—Typical four-way manhole.

bility of seepage through the joints. A quick-setting cement is recommended, and the mortar should be as dry as practicable to obtain adhesion. After the top layer of ducts is in place, all exposed joints should be thoroughly covered by a coating of cement mortar, applied with a trowel. A mandril should be drawn through each duct as it is laid; the mandril to be of a diameter ¼ in. less than the interior diameter of the duct. The length of this mandril should be about 36 in. The mandril should be left in each duct until the next succeeding duct is laid. The space between ducts and sides of ditch, which space should in no case be less than 3 in., and for a depth of 3 or 4 in. above the duct should be filled with cement concrete. Each layer of concrete should be thoroughly rammed as it is put in. The top of the finished conduit should not be less than 2 ft. below the surface of the street.

Manholes. Manholes should be placed at street intersections or turns and wherever necessary to make cable joints. The distance between manholes should not exceed 500 ft. A manhole should be kept well ventilated, dry and clean. Figs. 40 and 41 show typical brick two- and four-way manholes, respectively, from the Miscellaneous Methods of the American Electric Railway Engineering Association. The top of the manhole casting should be set so as to conform to the grade line of the street and the space between the bottom of the casting and the covering slab should be filled with brickwork laid in cement mortar. All bricks used should be of the best quality, whole, sound, perfect, and hard burned throughout. Every brick should be thoroughly wet by immersion in water previous to laying. In laying, each brick should have a full, close joint of cement mortar made at one operation on its bed, ends and sides. All joints must be thoroughly trowel struck. If the manhole is to be constructed of concrete, its walls, floor and ceiling should not be of thickness less than shown in Figs. 40 and 41.

Third Rail

Limiting Clearance Lines for Third-rail Structures, A.E.R.E.A. Standard. Fig. 42 gives the standard locations of the limiting clearance lines for third-rail and permanent way structures and rolling equipment. The space within the lines *AT*, *BT*, *CT*, *DT*, *ET*, *FT*, and *AT*, *JT*, *KT*, *LT*, *MT* should be reserved for third-rail structures on tangent track or curves of radius greater than 800 ft. (For curves of radius less than 800 ft. see notes in Fig. 42.) Permanent way structures on tangent track or curves of radius greater than 800 ft. should not be nearer the third-rail structure than lines *AS*, *JS*, *KS*, *LS*, *MS*. (For curves of radius less than 800 ft. see note in Fig. 42.) Rolling equipment under conditions of maximum wear and deflection on tangent track or curves of radius greater than 800 ft. should not be nearer the third-rail structure than lines *AE*, *BE*, *CE*, *DE*, *EE*, *FE*, *GE*. (For curves of radius less than 800 ft. see note in Fig. 42.)

Location of Third Rail, A.I.E.E. Standard. The gage line of the third rail to be located not less than 26 in. and not more than 27 in. from the gage line of the track, and the contact surface of the third rail to be not less than 2¾ in. nor more than 3½ in. above the plane of the top of the track rail.

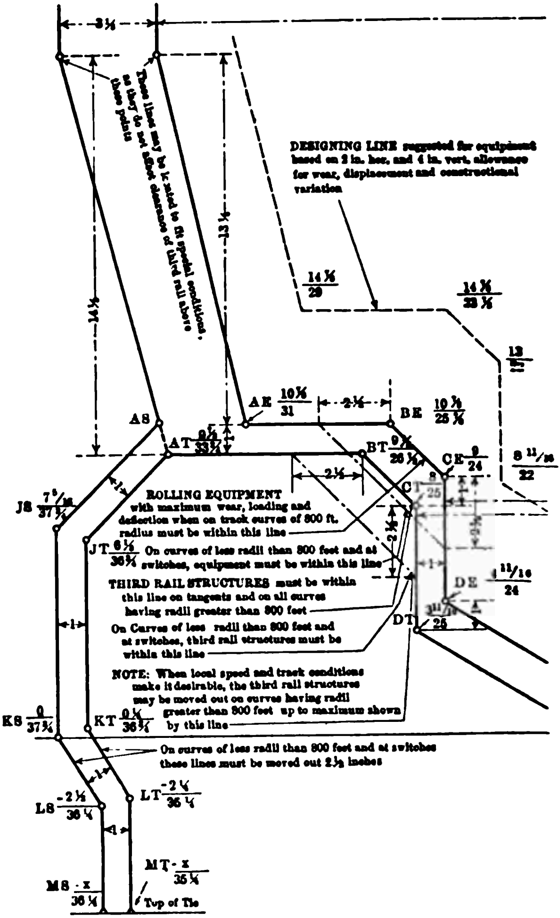
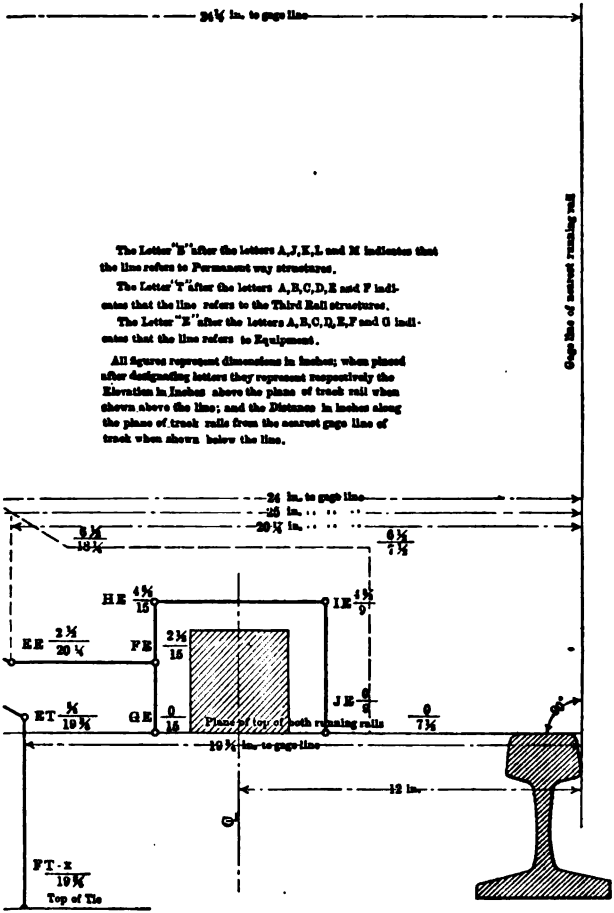

3½
These lines may be located to fit special conditions, as they do not affect clearance of third rail above these points
14½
13½
DESIGNING LINE suggested for equipment based on 2 in. hor. and 4 in. vert. allowance for wear, displacement and constructional variation
14½/29
14½/23½
13
AE 10½/31
2½
BE 10½/25½
AS
AT 9½/33½
BT 9½/26½
CE 9/24
8 11/16 / 22
2½
CT 8/25
J8 7 5/16 / 37½
1
ROLLING EQUIPMENT with maximum wear, loading and deflection when on track curves of 800 ft. radius must be within this line
JT 6½/36½
On curves of less radii than 800 feet and at switches, equipment must be within this line
2½
1
THIRD RAIL STRUCTURES must be within this line on tangents and on all curves having radii greater than 800 feet
DE 4 11/16 / 24
On Curves of less radii than 800 feet and at switches, third rail structures must be within this line
DT 3 11/16 / 25
1
NOTE: When local speed and track conditions make it desirable, the third rail structures may be moved out on curves having radii greater than 800 feet up to maximum shown by this line
KS 0/37½
KT 0½/36½
On curves of less radii than 800 feet and at switches these lines must be moved out 2½ inches
1
LS -2½/36½
LT -2½/36½
1
MT -x/35½
MS -x/36½
Top of Tie

FIG. 42.—Standard limiting clearance lines for third rail.

Third-rail Gage, A.E.R.E.A. Standard Definition. Distance measured parallel to plane of the top of both running rails, between gage line of running rails and gage line of third rail.

Composition and Resistance of Third Rail. The following tables and conclusions regarding the composition of steel and iron conductor rail are from a paper by Mr. J. A. Capp before the American


34¼ in. to gage line
The Letter "E" after the letters A, J, K, L and M indicates that the line refers to Permanent way structures.
The Letter "T" after the letters A, B, C, D, E and F indicates that the line refers to the Third Rail structures.
The Letter "E" after the letters A, B, C, D, E, F and G indicates that the line refers to Equipment.
All figures represent dimensions in inches; when placed after designating letters they represent respectively the Elevation in Inches above the plane of track rail when shown above the line; and the Distance in inches along the plane of track rails from the nearest gage line of track when shown below the line.
Gage line of nearest running rail
24 in. to gage line
25 in. " " "
20½ in. " " "
6½ / 18¾
6½ / 7½
HE 4½ / 15
IE 4½ / 9
EE 2½ / 20¼
FE 2½ / 15
JE 0 / 9
ET ½ / 19¾
GE 0 / 15
Plane of top of both running rails
0 / 7½
19¾ in. to gage line
12 in.
FT-E / 19¾
Top of Tie

permanent way structures and rolling equipment.

Institute of Mining Engineers, 1903. The table on page 676 gives temperature and specific resistance at that temperature, conductivity and resistance, compared to that of copper, and the composition for each of several samples of steel and iron tested. The samples

RESISTANCE AND COMPOSITION OF STEEL AND IRON*

Serial number	Specific resistance		Conductivity	Resistance	Percentage composition						
	Microhms Cm per Cm²	Temp. ° C.	Matthiessen standard	Cu. = 1	C	Mn	P	S	Si	Total not Fe	P + S + Si
1	22.72	19.0	7.58	13.20	0.33	1.27	0.09	0.05	0.05	1.79	0.19
2	20.90	20.0	8.27	12.12	0.17	1.09	0.09	0.05	0.004	1.404	0.144
3	21.29	25.0	8.27	12.09	1.40	0.222	0.01	0.020	0.082	1.734	0.112
4	19.87	19.0	8.65	11.55	0.20	0.95	0.10	0.08	0.05	1.38	0.23
5	19.80	19.0	8.68	11.51	0.43	0.77	0.10	0.04	0.066	1.406	0.206
6	19.80	19.0	8.69	11.51	0.36	0.80	0.10	0.04	0.047	1.347	0.187
7	19.81	20.0	8.69	11.51	0.22	1.08	0.10	0.05	0.06	1.510	0.210
8	19.69	19.0	8.73	11.44	0.74	0.58	0.043	0.036	0.20	1.599	0.279
9	18.95	25.0	9.29	10.76	1.61	0.147	0.015	0.018	0.092	1.882	0.125
10	18.17	19.0	9.46	10.56	0.41	0.72	0.039	0.041	0.11	1.32	0.190
11	17.27	19.0	9.96	10.04	0.36	0.87	0.08	0.09	0.04	1.44	0.21
12	17.10	19.0	10.06	9.94	0.37	0.73	0.09	0.04	0.06	1.29	0.19
13	17.10	19.5	10.06	9.94	0.23	0.80	0.046	0.033	0.016	1.095	0.065
14	16.96	19.0	10.14	9.86	0.30	0.95	0.063	0.01	0.01	1.333	0.083
15	16.95	19.5	10.14	9.86	0.29	0.99	0.084	0.01	0.01	1.384	0.104
16	16.32	19.0	10.55	9.48	0.23	0.89	0.053	0.01	0.005	1.193	0.073
17	16.25	19.5	10.59	9.44	0.26	0.83	0.053	0.01	0.004	1.157	0.067
18	16.21	20.0	10.62	9.42	0.28	0.65	0.083	0.06	0.05	1.123	0.193
19	16.09	19.0	10.60	9.36	0.22	0.68	0.077	0.07	0.05	1.097	0.197
20	16.09	19.0	10.69	9.36	0.16	0.66	0.074	0.030	0.014	0.938	0.118
21	15.32	19.0	11.24	8.90	0.33	0.49	0.068	0.05	0.02	0.958	0.138
22	14.57	19.5	11.82	8.46	0.31	0.45	0.10	0.04	0.026	0.926	0.166
23	14.49	20.0	11.88	8.42	0.25	0.41	0.10	0.04	0.03	0.83	0.17
24	14.73	23.5	11.88	8.42	0.144	0.46	0.09	0.08	tr.	0.774	0.17
25	14.62	23.5	11.96	8.36	0.188	0.48	0.09	0.08	tr.	0.83	0.17
26	14.15	19.0	12.17	8.22	0.22	0.56	0.024	0.34	tr.	0.838	0.058
27	14.03	19.0	12.26	8.16	0.192	0.57	0.024	0.34	tr.	0.82	0.058
28	13.86	19.0	12.41	8.06	0.16	0.48	0.091	0.04	0.01	0.781	0.144
29	13.83	19.5	.2.44	8.04	0.10	0.55	0.08	0.05	0.024	0.804	0.154
30	13.80	19.0	12.57	8.02	0.14	0.41	0.11	0.05	0.009	0.719	0.169
31	13.67	19.0	12.58	7.95	0.23	0.48	0.024	0.01	0.023	0.767	0.057
32	13.64	19.0	12.61	7.93	0.24	0.57	0.029	0.01	0.003	0.850	0.042
33	13.90	24.0	12.63	7.92	0.10	0.25	0.04	0.02	0.05	0.46	0.11
34	13.31	19.0	12.92	7.74	0.25	0.37	0.04	0.03	0.018	0.708	0.088
35	13.30	19.5	12.94	7.73	0.23	0.49	0.024	tr.	0.004	0.748	0.028
36	13.27	19.0	12.97	7.71	0.19	0.37	0.09	0.05	0.01	0.71	0.15
37	13.25	19.0	12.99	7.70	0.27	0.41	0.024	0.01	0.001	0.715	0.035
38	13.18	19.0	13.05	7.66	0.28	0.28	0.027	0.034	0.04	0.661	0.111
39	13.18	19.0	13.05	7.66	0.07	0.40	0.08	0.07	0.013	0.633	0.163
40	13.07	19.0	13.16	7.60	0.28	0.42	0.022	0.04	0.008	0.770	0.070
41	12.87	20.0	13.27	7.48	0.16	0.38	0.08	0.04	0.009	0.669	0.129
42	12.73	20.0	13.52	7.40	0.15	0.45	0.011	0.033	tr.	0.644	0.044
43	12.69	19.0	13.55	7.38	0.19	0.21	0.025	0.04	0.034	0.499	0.099
44	12.53	19.0	13.74	7.28	0.215	0.22	0.051	0.113	.....	0.599	0.164
45	11.01	19.0	15.63	6.40	0.05	0.19	0.054	0.059	0.03	0.383	0.143
46	13.80	25.5	12.78	7.82	0.15	0.068	0.13	0.02	0.15	0.518	0.30
47	13.82	26.0	13.37	7.48	0.15	0.064	0.036	0.02	0.13	0.400	0.186
48	13.10	26.0	13.50	7.41	0.16	0.074	0.12	0.027	0.10	0.481	0.247
49	12.54	25.5	14.07	7.11	0.08	nil	0.13	0.008	0.024	0.242	0.162
50	11.92	25.5	14.80	6.76	0.17	0.027	0.074	0.022	0.077	0.370	0.173
51	10.82	24.0	16.21	6.17	0.058	0.10	0.014	tr.	0.012	0.184	0.026
52	10.80	25.5	16.34	6.12	0.16	0.018	0.049	0.011	0.015	0.252	0.075
LSS	11.40	17.0	15.00	6.68	0.050	0.180	0.013	0.011	0.02	0.274	0.044
B	11.00	17.0	15.57	6.44	0.030	0.036	0.065	0.016	0.14	0.287	0.221
SCI	10.35	17.0	16.55	6.06	0 028	tr.	0.004	0.005	0.07	0.107	0.079

* Serial numbers 1 to 45 inclusive are steel.
Serial numbers 45 to end of table are iron.

having serial numbers, 1, 2, 4, 7, 11 and 12 were standard T-rails. Nos. 24 and 25 were cut from T-rail used for conductor on the Aurora, Elgin and Chicago R. R. Nos. 46, 47 and 48 were ordinary refined bar-iron; 49 and 50 were special refined bar-iron for stay-bolts and similar use, 51 and 52 were Swedish and Norway iron respectively.

The values in the tables showing the variation of resistance with manganese were selected from the table on page 676 in studying the influence of manganese on resistance and indicate that the effect of manganese in increasing resistance gradually increases with the percentage of manganese present, within the limits represented by these samples. Messrs. Barrett, Brown and Hadfield (Trans. Royal Dublin Society, Vol. VII, series 2, Part IV) found the resistance to increase at first very rapidly, with constantly increasing percentage of manganese, then more and more slowly, until 7 per cent. manganese, after which a further increase in the percentage of manganese produces little or no increase in resistance.

RESISTANCE OF STEEL. VARIATION WITH MANGANESE

(Carbon from 0.17 to 0.23 per cent.)

Sample number	Manganese, per cent.	Resistance	Carbon, per cent.	P + S + Si per cent.
2	1.09	12.12	0.17	0.144
4	0.95	11.55	0.20	0.23
7	1.08	11.51	0.22	0.210
13	0.80	9.94	0.23	0.065
16	0.89	9.48	0.23	0.073
19	0.68	9.36	0.22	0.197
25	0.48	8.36	0.188	0.17
26	0.56	8.22	0.22	0.058
27	0.57	8.16	0.192	0.058
31	0.48	7.95	0.23	0.057
35	0.49	7.73	0.23	0.028
36	0.37	7.71	0.19	0.15
43	0.21	7.38	0.19	0.099
44	0.22	7.28	0.215	0.164

RESISTANCE OF STEEL. VARIATION WITH MANGANESE

(Carbon from 0.27 to 0.33 per cent.)

Sample number	Manganese, per cent.	Resistance	Carbon, per cent.	P + S + Si per cent.
1	1.27	13.20	0.33	0.19
14	0.95	9.86	0.30	0.083
15	0.99	9.86	0.29	0.104
18	0.65	9.42	0.28	0.193
21	0.49	8.90	0.33	0.138
22	0.45	8.46	0.31	0.166
37	0.41	7.70	0.27	0.035
38	0.28	7.66	0.28	0.111
40	0.42	7.60	0.28	0.070

The values in the tables showing the variation of resistance with carbon were selected from the table on page 676 in studying the influence of carbon on resistance. With uniformly increasing carbon the resistance of unhardened steel at first rises very rapidly, but the rate of increase gradually drops until it reaches a straight line at about 0.2 per cent. C., which continues up to limits of the carbon listed.

RESISTANCE OF STEEL. VARIATION WITH CARBON
(Manganese from 0.15 to 0.30 per cent.)

Sample number	Carbon, per cent.	Resistance	Manganese, per cent.	P + S + Si per cent.
3	1.40	12.09	0.222	0.112
9	1.61	10.76	0.147	0.125
33	0.10	7.92	0.25	0.11
38	0.28	7.66	0.28	0.111
43	0.19	7.38	0.21	0.099
44	0.215	7.28	0.22	0.164
45	0.05	6.40	0.19	0.143

RESISTANCE OF STEEL. VARIATION WITH CARBON
(Manganese from 0.4 to 0.5 per cent.)

Sample number	Carbon, per cent.	Resistance	Manganese, per cent.	P + S + Si per cent.
21	0.33	8.90	0.49	0.138
22	0.31	8.46	0.45	0.166
23	0.25	8.42	0.41	0.17
24	0.144	8.42	0.46	0.17
25	0.188	8.36	0.48	0.17
28	0.16	8.06	0.48	0.144
30	0.14	8.02	0.41	0.169
31	0.23	7.95	0.48	0.057
35	0.23	7.73	0.49	0.028
37	0.27	7.70	0.41	0.035
39	0.07	7.66	0.40	0.163
40	0.28	7.60	0.42	0.070
42	0.15	7.40	0.45	0.044

The following is also from Mr. Capp's paper: "The elements phosphorus, sulphur and silicon were not present in sufficient quantity in any of the samples tested to permit us to draw any curves showing their influence upon the resistance. . . . In commercial steels the percentages of all three of these elements is so small that their effect on resistance may generally be neglected. A study of the several tables given in the paper shows that manganese preponderates in influencing the resistance of steels, and that for lowest resistivity, this element must be present in very small quantity, much smaller than is usual in merchant or structural steels. While all the other elements must be present only in very small percentages, so great is the preponderance of the influence of manganese, that they may be tolerated in quantities which the steel makers would consider reasonable, without unduly increasing the resistance. For a satisfactory third rail the lowest possible resistance (from 6 times to 6.5 times that of copper?) is not necessary; and the great cost of making such extremely pure steel is not warranted. In fact, such extremely pure steels would probably be so soft that the frictional wear of the collecting shoe would be excessive and the life of the rail unduly short. Assuming, then, that a rail from steel having a resistance not greater than eight times that of copper (13.8 microhms at 20 deg. C.) would be desirable for conductor rails, the figures tabulated would seem to indicate that the following extreme composition would be permissible:

	Per cent.
Carbon up to	0.2
Manganese up to	0.4
Phosphorus up to	0.06
Sulphur up to	0.06
Silicon up to	0.05

This composition, however, would be extreme, and any overstepping of bounds might result in too great resistance; therefore for resistance up to eight times that of copper, the specified analysis should be:

	Per cent.
Carbon not to exceed	0.15
Manganese not to exceed	0.30
Phosphorus not to exceed	0.06
Sulphur not to exceed	0.06
Silicon not to exceed	0.05

The following suggested third-rail composition is from the Standard Handbook for Electrical Engineers:

	Per cent.
Carbon not to exceed	0.12
Manganese not to exceed	0.40
Sulphur not to exceed	0.05
Phosphorus not to exceed	0.10

Relative to conductor rails installed by the Underground Electric Rys. Co., London., Mr. S. B. Fortenbaugh (paper A.I.E.E., 1908), says: "The resistance of these rails was about 6.4 times that of an equivalent area of copper and the chemical composition substantially as follows:

	Per cent.
Carbon	0.05
Manganese	0.19
Sulphur	0.06
Phosphorus	0.05
Silicon	0.03

It is interesting to note that the cost of this special conductor rail was no more than the standard track rail."

British Standard Method of Specifying Resistance of Steel Conductor Rails. The British Engineering Standard Committee has adopted (1914) the following: In specifying the resistance of a steel conductor rail the value shall be given in microhms (millionths of an ohm) and shall be expressed as the resistance in microhms at a temperature of 60 deg. F. (15.6 deg. C.) of a rail of the same material as the conductor rail in question, having a length of 1 yd. and a weight of 100 lb. It follows that if the resistance of a rail weighing 100 lb. to the yard be R_s microhms, that of a rail weighing W lb. to the yard will be $\frac{100R_s}{W}$ microhms. Conversely, if the resistance of a rail 1 yd. in length weighing W lb. to the yard be R_w microhms, that of the corresponding 100-lb. rail will be $\frac{WR_w}{100}$ microhms. In either case we have the relation $100R_s = WR_w$. For the purpose of reducing observations made at temperatures other than 60 deg. F. to the standard temperature, a mean coefficient of increase of resistance with temperature of 0.26 per cent. per deg. F. (0.47 per cent. per deg. C.) shall be employed unless otherwise specified. Where greater accuracy is required for a wide range of temperature, the coefficient of the actual piece of rail should be used.

Temperature Coefficient of Conductor Rails. Commenting on the above, the British Committee notes that the temperature coefficient of the conductor rails tested at the National Physical Laboratory for the purpose of the report varied from 0.28 per cent. per deg. F. (0.51 per cent. per deg. C.) for a rail of 15.9 microhms per 100-lb. yard to 0.24 per cent. per deg. F. (0.43 per cent. per deg. C.) for a rail of 20.5 microhms per 100-lb. yard. Taking the extreme case of a rail of 16 microhms per 100-lb. yard tested at 40 deg. F. (4.5 deg. C.) or 80 deg. F. (27 deg. C.), the use of the mean temperature coefficient may introduce an error of ±0.6 per cent. For a smaller range of temperature the error would be proportionately less.

National Physical Laboratory Tests. The above-mentioned report of the British Engineering Standards Committee gives the following table showing the relation between the resistance, temperature coefficient and composition of some samples tested at the National Physical Laboratory for the purpose of the report. (Sample 1 is electrolytic iron; 2, 3, 4 and 5 are conductor rails; 6 is a piece of ordinary track rail.)

Sample	Microhms per 100-lb. yard	Relative resistivity		Temp. coeff. per cent. per deg. C.	Carbon	Silicon	Sulphur	Phosphorus	Manganese	Arsenic	Copper	Nickel	Chromium
		Mass	Volume										
1	13.9	5.00	5.67	0.55	....	....	....	....	....	....	....	....	.....
2	15.9	5.72	6.48	0.51	0.040	Trace	0.044	0.035	0.165	0.030	0.025	0.047	Trace
3	16.9	6.08	6.89	0.47	0.035	0.011	0.076	0.017	0.100	0.028	0.005	0.330	Trace
4	18.35	6.59	7.47	0.45	0.092	Trace	0.097	0.072	0.362	0.065	0.046	0.094	Trace
5	20.5	7.38	8.37	0.43	0.403	Trace	0.060	0.027	0.365	0.012	0.048	0.081	Trace
6	25.3	9.1	10.3	0.35	0.561	0.068	0.028	0.066	0.605	0.021	....	....	.....

Third-rail Sections. Both T-rails and rails of specially rolled sections are used for third rail. The section should be such as to offer ample surface for current collection, and it should have an area of cross-section proportional to the conductivity desired. The following table gives the weight per yard of the T-rail used for third n several installations:

Road	Weight of third rail, lb. per yd.
Englewood Elevated, Chicago	48
Metropolitan West Side Elevated, Chicago	48
Northwestern Elevated, Chicago	48
Grand Rapids, Grand Haven & Muskegon	60
Michigan United Railways	60
Interborough Rapid Transit Co., New York	75
Interborough Rapid Transit Co. (Westchester branch)	75
Lackawanna & Wyoming Valley	75
Wilkes-Barre & Haselton	80
Boston Elevated	85
Aurora, Elgin & Chicago	100
Interborough Rapid Transit (elevated division)	100
Long Island R.R	100
Puget Sound Elec. Ry	100
Scioto Valley Traction Co	100
Seattle-Tacoma Interurban	100
Pennsylvania Tunnel & Terminal R. R	150

The section shown in Fig. 43 was used in the New York Central & Hudson River R. R. electrification. Fig. 44 shows an inverted channel section devised by Messrs. S. G. Redman and C. H. Merz, London. This channel is of irregular form, as the non-contacting flange is used to secure more cross-sectional conductivity and to keep the contact-making flange in place.

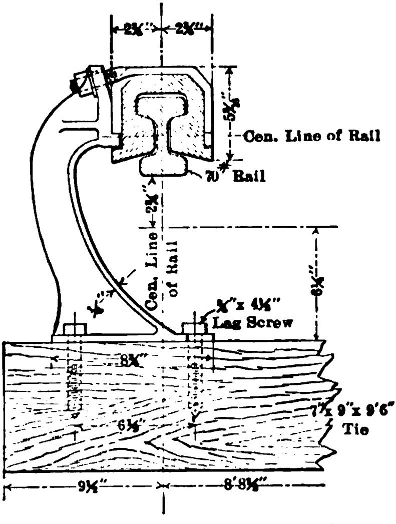


FIG. 43.—N. Y. C. type underrunning third rail.

Third-rail Support. The 1908 report of the Committee on Power Distribution, A.E.R.E. A. states "The spacing of third-rail supports varies without respect to the type of rail. The spacing most used is that of 10 ft., with a maximum in some instances of 11 ft. and a minimum of from 5 ft. to 6 ft. These locations are apparently governed by the lengths of third rail and the standard tie spacing in use. The weights of brackets vary between 9 lb. with the overrunning rail and 13 lb. to 20 lb. for the underrunning rail. The committee can see no reason for such great diversity in spacing of supports, and would recommend that a spacing of 10 ft. be used on all third-rail construction where 30-ft. conductor rail is used, and 11 ft. where 33-ft. conductor rail is used. In all cases but one (reported), the support for the bracket is an extended tie, which is also a part of the track structure. In the one case referred to (subway of the Philadelphia Rapid Transit Co.), it is entirely independent of the track structure. It might be well in this connection to note that the road referred to reports an absolute lack of insulator breakage, undoubtedly accounted for by the above condition of supports independent of track structure." Fig. 45 shows the method of supporting the overrunning T-section third rail on the Philadelphia & Western Ry. Fig. 46 shows the method of supporting the underrunning T-section third rail on the 1200-volt interurban division of the Central California Traction Co. Fig. 43 shows the method of supporting the underrunning third rail on the New York Central & Hudson River R. R. Fig. 44 shows the method of supporting the Redman-Merz underrunning third rail. The rectangular base of this channel is supported on a flat insulator, an intermediate bracket and a foundation insulator. The capping of the conductor channel may be of fiber, stoneware, or other material keyed into the conductor as indicated.

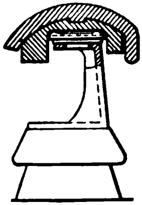


FIG. 44.—Inverted channel third rail.

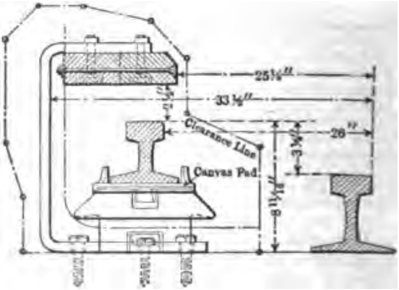


FIG. 45.—Third rail and support, Phila. & Western.

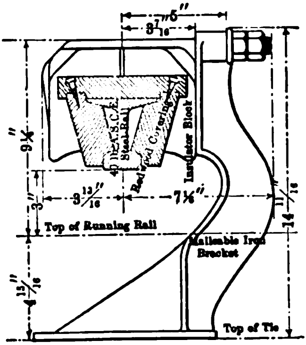


FIG. 46.—Underrunning (T) third rail, California.

Third-rail Insulation. The 1908 report of the Committee on Power Distribution, A.E.R.E.A. states "Three kinds of insulation are used with the overrunning type of rail: wood, reconstructed granite and composition. Four kinds of insulation are used in the underrunning type: wood, porcelain, semi-porcelain and composition. The breakage of insulators for the overrunning types reported is 2.76 per cent. per year. The breakage on the underrunning type is 3.36 per cent. per year, based on the information now in the hands of the committee."

Relative to experience on the Long Island R. R., the Street Ry. Journal, 1907, states that the chief causes of the failure of insulators are breakage or chipping of the glazed surface due to rail movement, burning of the insulators due to excessive moisture trickling down over the surface, displacement due to creeping of the third rail, and breakage due to derailments. A considerable amount of the leakage over the insulators, which would finally result in burning them, has been corrected by cleaning off the dirt with a piece of cloth.

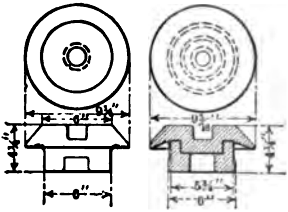


FIG. 47.—Third-rail insulator, Phila. & Western.

Relative to the use of the underrunning U-section third rail on the Philadelphia & Western Ry., the Electric Ry. Journal, 1912, states that experience had shown that while the original undercontact rail provided for longitudinal movement due to expansion and contraction, no provision had been made for movement in a vertical plane. The vibrations set up by heavy cars brought such enormous strains upon the insulators that in many places the only insulation left was that afforded by the tie. Fig. 47 shows two types of insulators used in the installation shown in Fig. 45. The one-piece insulator is dry-process porcelain and the two-piece insulator is wet-process porcelain. A cast-iron cup with lag screw holds the insulator in place on the tie and a cast-iron cap on top of the insulator holds the third rail in position. A canvas pad between this cap and the insulator, together with provision for vertical movement, reduces the vibration which is so destructive to the porcelain. In the installation shown in Fig. 46 a porcelain block is used at each bracket. In the installation shown in Fig. 43 the third rail is loosely held in each bracket by noncharring, moisture-proof insulator blocks. Fig. 48 shows a two-piece porcelain insulator used on the Lackawanna & Wyoming Valley R. R. The two pieces of porcelain are cemented together as shown and then mounted on a wooden pin.

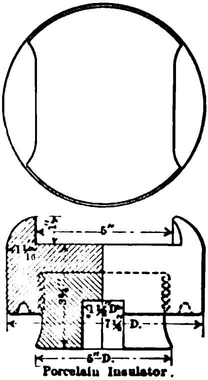
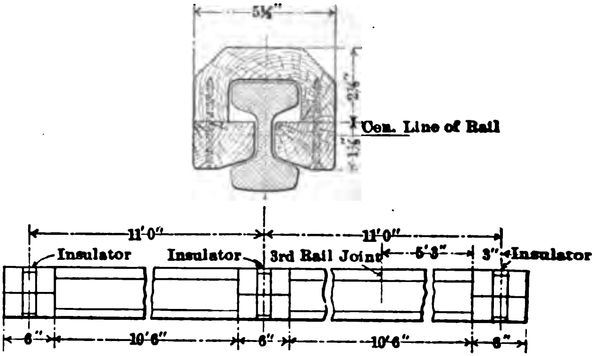


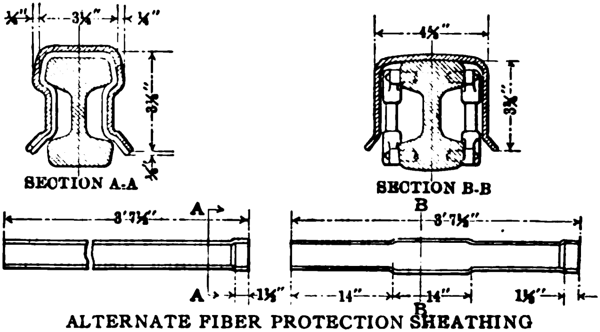
FIG. 48.—Third-rail insulator, Lackawanna & Wyoming Valley.

Third-rail Protection. Methods of protecting overrunning and underrunning T- and U-section third rail are shown by Figs. 43 to 45, respectively. The details of two types of protection used on the New York Central type third rail (Fig. 43) are given in Fig. 49. In this type a sheathing of wood or fiber reaching from bracket to bracket embraces the rail head, reaches nearly to the running face of the rail and extends outward from the wed, thus forming a petticoat.

Operation of Third Rail in Snow. In Feb., 1906, tests of the operation of third rail in snow were made on the New York Central & Hudson River R. R. After medium heavy snow had fallen without drifting, to an average depth of 17 in. a flanger was sent over the track. This packed the snow against the third rail. The test was made by observing the operation during the passage of an electric locomotive on several trips. During the first passage over the overrunning unprotected third rail there was very little flashing or trouble. Due to the formation of ice and the ironing out of snow, operation grew worse on succeeding passages until it became almost impossible. Results with the overrunning protected third rail were about the same as with the overrunning unprotected third rail. The first passage scooped the snow away for 2½ or 3 in. under the contact surface of the underrunning protected third rail. Each succeeding passage tended to clean the contact surface and operation was practically free from trouble.



INSULATOR AND WOODEN PROTECTION SHEATHING



ALTERNATE FIBER PROTECTION SHEATHING

FIG. 49.—Protection for N. Y. C.-type third rail.

Operation of Third Rail in Sleet. In March, 1906, tests of the operation of third rail after a sleet formation was made on the New York Central & Hudson River R. R. The sleet formation continued for a day in a wind having a velocity of about 2 miles an hour and temperature ranging from 28 to 33 deg. F. The thickness of the sleet averaged about ¼ in. The effect of the sleet on the overrunning unprotected third rail was so bad that running was impossible after 3 hours. In places where the wind caused the sleet to distribute entirely over the running surface of the rail the contact shoes arced badly and the operation was unsatisfactory. There was no sleet formation on the running surface of the underrunning rail and there was no sign of arcing.

Mechanical Third-rail Sleet Remover. A type of third-rail sleet shoe designed by Mr. W. Silms, and which is giving satisfaction on the Michigan United Railways, is shown in Fig. 50. It is of the same design as the regular third-rail shoe, but has four steel cutters set diagonally in its face and cast integral with the body of the shoe. When these cutting edges become worn or damaged they are chipped off, and the shoe is kept in regular service until it is worn out. The sleet-cutting shoe is mounted on a vertical iron shaft which passes through guides and is attached to the piston of an air cylinder which has a 3-in. stroke. A spiral spring around this shaft holds the shoe off the rail except when air pressure is put on the cylinder to press the cutters against the rail. The air supply is taken from the train line through a ⅜-in. three-way valve and pipes extending under the car to a point convenient for connecting with the cylinder which operates the shoe. This connection between the pipes and the cylinder is made with 2½-ft. lengths of ⅜-in. air hose, secured at each end with hose clamps. An ordinary straight valve is placed in each supply pipe to enable the motorman to use one or both shoes as occasion demands.

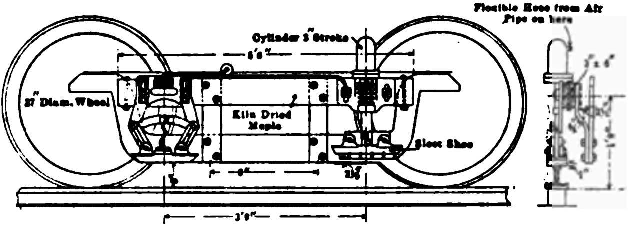


FIG. 50.—Third-rail sleet shoe, Michigan United.

The third-rail sleet-removing device shown in Fig. 51, developed by the Metropolitan West Side Elevated R. R. Co., was found by that company to give satisfactory service under all operating and weather conditions. The device consists of a piece of oak 2⅝ in. × 5½ in. × 4 ft. 1¾ in., at one end of which crusher rolls are placed and at the other end are scrapers. The crushing rolls, 3¼ × 3¼ in. in size, are right and left spiral toothed, made of

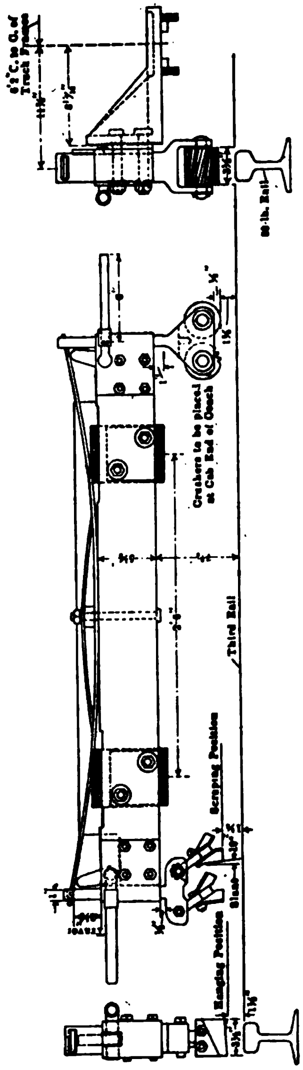
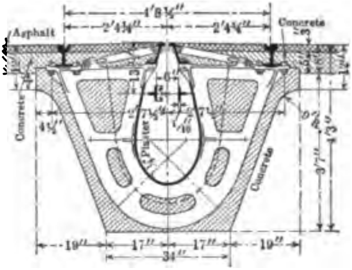

6½" C. to C. of Truck Frame
80-lb. Rail
Crushers to be placed at Cab End of Coach
Third Rail
Scraping Position
Slide
Hanging Position

FIG. 51.—Sleet-removing device—Metropolitan West-side Elevated.

cast crucible steel, hardened but not machined. These rollers are carried on 1 × 6-in. steel pins, which are held in place in the steel slide-rod casting by cotter pins at each end. At each end of the oak board is a cast-iron cam and wooden handle, which is used in raising or lowering the rollers or scrapers from or to the working position. The scraper blades are ¼ × 3¾ × 2⅜ in., and are made of tool steel. There are four of these blades bolted to cast-steel pivots so that they may take the scraping position for either a backward or forward movement of the car. The scrapers are supported on a slide rod provided with the elevating cam similar to the crushers. Immediately inside the guide plates which support the crusher and scraper slide rods are two cast-iron corrugated plates which are used in adjusting the sleet remover for different truck heights and wheel wear. Bolted to the top of the oak insulating timber is an adjusting leaf spring, the ends of which are fitted into slots provided at the top of each slide rod. At first this spring provided 100 lb. pressure at both the crusher and scraper, later the crusher end pressure was increased to 200 lb. by adding another leaf to the crusher end of the spring. This device may be either bolted to the third-rail shoe beam or held in position by means of a casting which is fitted to the car spring seats. A ½-in. flashboard made of ash and running the full length of the sleet remover is inserted between adjusting plates and the oak timber to provide additional insulation.

Calcium Chloride Third-rail Sleet Removal. On the Aurora, Elgin & Chicago Ry. a solution of calcium chloride made by dissolving caustic chloride of calcium in warm water in the proportion of 5 lb. of caustic chloride of calcium to 1 gal. of water has been used in the removal of sleet from the third rail and the prevention of the formation of a coat of sleet on the rail. The solution was kept in a 40-gal. tank in the motorman's cab and was led through a rubber tube to a ¼-in. pipe from which it was squirted upon the third rail a few inches in front of a steel sleet brush. The flow of liquid was controlled by a globe valve. The pipe was grounded to the truck frame. There were four sleet brushes per car and each was provided with a pipe. In operation only the forward pipe on the third-rail side was used. The flow of liquid was regulated according to the speed of the train and about 1 gal. per mile was required. The sleet brush immediately behind the pipe spread the liquid uniformly over the surface of the rail. A thin sleet formation was dissolved and direct contact was made with the third rail. A thicker sleet formation was not melted at once, but was so loosened that it was scraped off the rail by the passage of one or two sleet brushes. The formation of new ice was prevented as long as the liquid remained on the rail, but after about 2 hours the liquid was removed to such an extent that another application was necessary. This process removed the sleet and kept the trains in operation, but it had a bad effect on the insulation of the third rail and car wiring. This led to the development of a side contact shoe having a cross-section similar to an inverted V. By riding on the edges of the third rail this shoe either removes the sleet or makes contact where the sleet is thinnest.

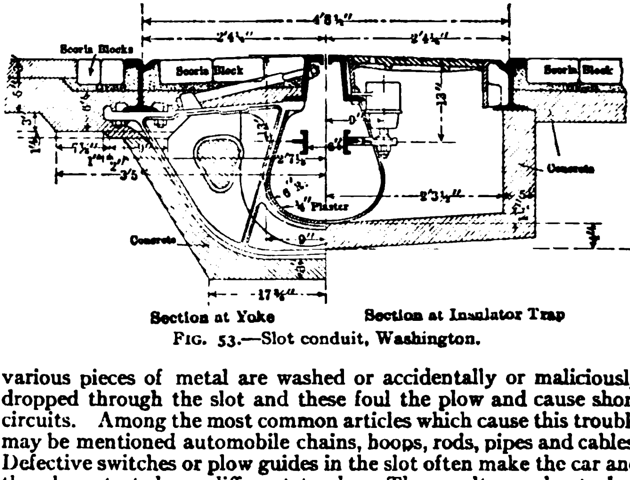


Section at Yoke

FIG. 52.—Cable conduit rebuilt for electric operation.

Conduit System. Fig. 52 shows a section of cable conduit as rebuilt for electrical operation, and Fig. 53 shows a standard section of conduit, both as used in Washington, D. C. These are from a paper by Mr. J. H. Hanna, Aera, 1913. The essential elements of this conduit system consist of cast-iron yokes supporting both wheel and slot rails and two steel "T" shaped conductor bars supported from the bottom flange of the slot rail by insulators. The wheel rails are fastened with four hook bolts at each yoke seat with liners driven back of the bolts to allow accurate lining and gaging of the rails after the yokes have been concreted. The conduit proper is of concrete with concrete manholes at each insulator, spaced 15 ft. apart. Insulators consist of malleable caps with lugs by which the insulator is bolted to the slot rail porcelain insulators and forged studs cemented together, the latter supporting the conductor rail by means of adjustable malleable clips or brackets. The slot rail weight is 67 lb., and conductor bar, 22.4 lb. per yard. Yokes are spaced 5 ft. apart and weigh about 350 lb. each. The conductor bars are connected with underground feeder cables at intervals varying from 800 ft. for lines having dense traffic to much greater intervals in outlying districts. The distribution system is identical for positive and negative sides and is controlled at substations by double-pole double-throw switches, which make it possible to reverse the polarity if necessary on account of grounds on different sides of different circuits.

The conduit system is a constant source of trouble to both the railway company and the traveling public. It is by far the least reliable of all the systems. This is because of the difficulties of ordinary operation and the excessive number of accidents which are possible with this system and against which it is impossible to provide. Neglecting accidents, for the moment, this system is the most difficult to keep in ordinary operation. The ordinary difficulties reach a maximum with rain and snow storms. Snow tends to fill the conduit and must be removed by pushing it to manholes by scrapers. These manholes must be kept clean. The removal of snow interferes with traffic. To return to the purely accidental, various pieces of metal are washed or accidentally or maliciously dropped through the slot and these foul the plow and cause short circuits. Among the most common articles which cause this trouble may be mentioned automobile chains, hoops, rods, pipes and cables. Defective switches or plow guides in the slot often make the car and the plow start down different tracks. The results are bent plow bars, broken yokes, bent and grounded plows. Locating a ground in this system is often a slow process during which traffic is tied up.



Section at Yoke Section at Insulator Trap

FIG. 53.—Slot conduit, Washington.

Auto-transformer Scheme of Single-phase Distribution. In the auto-transformer scheme (also known as the semi-balanced system) of-single phase distribution developed on the New York, New Haven and Hartford R. R., the contact conductor of the 11,000-volt catenary system is connected to one side of a 22,000-volt single-phase line, auto-transformers distributed along the track are connected across this 22,000-volt line, and the middle point of each of these auto-transformers is grounded to the track rails. Thus this system is similar to a three-wire system except that the direct load is on one side of the circuit, the other side of the circuit receiving its share of the load through auto-transformers which act as balancers. By this system the operating economies of a contact conductor voltage of 11,000 and a transmission voltage of 22,000 are combined, and this has been done with the elimination of the disturbance which the ordinary single-phase system, having one side grounded and the other side connected to the contact conductor, caused in adjacent telephone and telegraph circuits.

Track Bonding

The following consideration of bonding deals with the application of electrical conductor to maintain good conductivity from rail to rail at the joints of the track circuit. This conductor serves no mechanical purpose at the joint. It should be noted that in city work the practice of joining the rails together by welding is increasing and that the use of additional electrical conductor is unnecessary where this is the practice. (See pp. 59–63.)

Classification of Bonds. Bonds may be classified according to the materials of which they are made, whether of solid copper, copper ribbon, or wire stranded copper; according to place of application to the rail, whether to the head, web or base, and if attached to web, whether "concealed" between joint plate and rail or "exposed" by being run over the outside of the joint plate; according to the method of attaching the terminal to the rail, whether compressed or expanded, brazed, soldered or amalgamated.

Compressed and Expanded Terminals. The bond terminal is forced into intimate contact with the walls of a hole drilled in the rail. The two general types of this terminal are commonly known as the "compressed (or stud) terminal" and the "pin terminal," respectively. The terminal of the compressed terminal bond is forced into contact with the wall of a hole in the rail by a screw or hydraulic press. The pin terminal is tubular and this tube is expanded into contact with the wall of a hole in the rail by driving a tapered steel pin into the bore of the tube. The following from the results of tests by the Chicago Board of Supervising Engineers, 1911, gives briefly some of the important points relative to the installation of these types of bonds:

First. Averaging the thirty-two tests on each type, the hydraulic compressed bond shows the least resistance, viz., about 96.65 per cent. of the pin terminal type. Stated in terms of conductivity, the pin terminal bond is 96.65 per cent. and the hand-compressed bond 98.64 per cent. of the hydraulic compressed bond considered as the standard, 100 per cent.

Second. The best form of terminal is that in which the flow of copper is into and not out of the bore, that is, one in which the flow is restricted. In this respect the compressed terminal is superior, although not so easy to apply as the pin terminal, and it also insures a much better mechanical attachment.

Third. A certain pressure between copper and steel is essential to good electrical contact. Conductivity improves up to about

35,000 lb. per square inch. With the pin terminal, however, it is found that around 20,000 lb. the copper begins to flow out of the bore and no higher contact pressure is possible on this account. This maximum is somewhat dependent upon the texture of the copper and the lubricant used, and upon the manner in which the pin is driven into place.

Fourth. General precautions to be taken in bonding as largely developed from these tests are as follows: Use only accurately ground drills, entered at right angles to the web, and finish smooth. The surface of the rail web should be cleaned for ½ in. around the bore, and the latter should be thoroughly cleaned and dried before bonding; thus the head of the bond will properly abut the web surface. In driving the pin a heavy lubricant should be used, first with a drift pin of the proper size (7/16 in. for a ¾-in. terminal), care being taken to avoid striking the bond itself.

Cost of Installing Compressed and Expanded Terminal Bonds. The following data from a paper by Mr. Carl H. Fuller, Electric Railway Journal, 1914, give actual costs of installing compressed and expanded terminal bonds on the tracks of the Macon Railway & Light Co., Macon, Ga. With the exception of the single case noted, all of the drilling was done with a Duntley electric track drill, the crew consisting usually of one man who ran the drill and a helper who helped him move the drill and pressed in the bonds. Both men removed and bolted up the plates as the occasion required. There is some slight gain in making the crew three men if the work warrants. The wage of the drill runner was $1.50 and of the helper $1.35 per day of 10 hours.

Case 1. Paving job. Track laid and surfaced, with two bolts in each splice. Bond crew removed the plates, drilled two holes, applied the concealed bond with a screw press and full-bolted the joint: 174 bonds at $0.2625 per bond.

Case 2. Installation of a cross-over in Belgian block paving. Bond crew drilled the holes, applied concealed or long bonds as required, full-bolted the joints; 35 bonds at $0.266 per bond.

Case 3. Repaving job. Old plates and bonds were not disturbed. Twenty-eight-inch bonds with compressed terminals were placed around the old plates. Bonding crew had a good chance to do record work and placed 128 bonds at $0.175 per bond.

Case 4. Paving job. Bond crew removed two bolts and plates, drilled for and placed concealed bond, replaced the plates with two bolts loose for track gang to finish: 199 bonds at $0.1825 per bond.

Case 5. Paving job. Bonding crew applied concealed bonds while track gang was laying track, but made no special effort to full-bolt the joints: 85 bonds at $0.168 per bond.

Case 6. Paving job. Track all surfaced, double track, bond crew following all four rails as they came to the joints, rails 60 ft. long, special effort to get low bonding costs, track gang applying the splice plates: 269 bonds at $0.09 per bond. This was an exceptional case and the same crew has never been able to break its own record.

Case 7. Laying track in dirt roads. Bond crew applied pin-compressed terminal bonds under the plates, doing the bolting up: 113 bonds at $0.136 per bond.

Case 8. Paving job. Remove plates with two bolts, drill two holes, compress bond and replace plates with four bolts, continuous work: 187 bonds at $0.235 per bond.

Case 9. Paving job. Remove plates, drill holes with hand drill, compress bond, replace the plates: 83 bonds at $0.375 per bond.

Case 10. Track laid in dirt road and fully surfaced. Remove plates with four bolts, drill holes and compress bond, replacing the plates. The four men in the crew worked continuously: 1020 bonds at $0.2405 per bond.

Case 11. Remove plates having four bolts, drill and press in bond, replacing plates: fifty-four bonds at $0.292 per bond.

Average cost of the total 2347 bonds in the above eleven cases is $0.215 per bond.

Brazed Terminals. "Brazed" bond terminals which are generally flat are brazed to a spot on the rail which has been prepared by grinding. The heat is supplied by a blow torch or heavy electric current. The brass used to make the brazed joint is used in a solder-like strip. A bond brazed electrically is sometimes called an electrically welded bond. The current is supplied at from 1 to 6 or 8 volts from a transformer which, on a direct-current road, is supplied by a motor-generator set operated on trolley voltage.

Soldered Terminals. Flat terminals are soldered to the rail or the end of a compressed or expanded terminal bond is soldered to the rail after the terminal has been compressed or expanded into place. The area over which the solder is to adhere to the rail is prepared by grinding. Heat is supplied by a blow torch or, in the case of the compressed terminal bond, the bond may be soldered by the Thermo bonding process, in which the necessary heat for soldering is obtained from the heat of reaction of a special compound which is ignited in a graphite cup held against the rail on the side opposite that to which the solder is to be applied.

Amalgamated Terminals. In one form a mass of tin amalgam is placed between amalgamated surfaces of rail and joint plate and is held in place by a cork washer squeezed between rail and joint plate. In another form the terminal of a copper bond and the surface of the rail or the walls of a hole in the rail are amalgamated and held in place with slight pressure, depending upon a layer of tin amalgam to maintain the contact. One method of using mercury amalgam is to apply it to the terminal surfaces of regular compressed or pin terminal bonds. The Chicago Board of Supervising Engineers, 1911, found the contact resistance of compressed and pin terminals with amalgamation to be approximately 94 per cent. of the contact resistance without amalgamation.

Bolted Terminals. In some types of bolted terminals copper strips are bolted against the rail or are squeezed between rail and joint plate. Bolted terminals have been developed particularly for applying the terminals of auxiliary cables around special work. For this latter purpose special terminals are bolted to the web of the rail.

Ideal Bond. The material, form and structure of the ideal bond are briefly presented by Mr. C. W. Ricker, A.I.E.E., 1905, as follows: To get the necessary conductivity, bonds are nearly always of copper, about the only exception being those of tin amalgam. To reduce cost and resistance, they must be as short as practicable, and the manufacturing cost must be kept low, to preserve the scrap value as near the first cost as possible. For durability they must be flexible enough so as not to break or lose contact by the allowable relative motion of the rails. They must be formed so they may be applied to the types of rails in ordinary use, in such position as to be protected from accidental damage and from theft. They should be readily accessible for inspection and repair. The cost of application must be kept low, and to this end it is very important that the process shall be so simple and easy that no highly skilled labor or extraordinary care is required to install them with certain and uniform results.

Failure of Bonds in Service. Failures of bonds may be placed in three classes, namely, (1) breakage of bonds, (2) disintegration of bonds, (3) impairment of contacts. The following discussion of these cases is from the above noted paper by Mr. C. W. Ricker:

Breakage of Bonds. Breakage may occur because of defects in manufacture, as in copper bonds with welded terminals the strands may be weakened by overheating where they enter the terminal; and a slight but continuous motion of the joint will cause them to break, one by one, at this place. Long-continued jar and repeated flexures will produce fatigue in the metal. Such breakage in the case of either welded or solid bonds is of course most frequent where the flexure of the bond due to rail movements is too great for its flexibility, which means ill-selected bonds or badly-kept track. A less common manner of breakage occurs in laminated underplate bonds which are too large for the space between the joint-plate and the rail, the bond shank is pinched and the working of the joint under passing wheels tears off the outer strands by a kind of ratchet effect, working them into the narrowing space at top or bottom of the rail-web and sometimes squeezing them out of the joint in thin ribbons. Bonds secured under the base of the rail may be frozen in the ballast and torn off by the movement of the rail.

Disintegration. The surfaces at the imperfect welds in composite bonds corrode, increasing the resistance greatly and loosening and weakening the bonds so that they may be pulled apart. Tin amalgam used at contacts or in masses, hardens and shrinks, losing flexibility and contact with the bonded surfaces. In the case of amalgam plugs enclosed in cork boxes, the cork sometimes breaks, allowing the soft amalgam to run out.

Impairment of Contact. By far the most important cause of impaired contact is oxidation. This is greatly facilitated by the presence of moisture, so that the slightest crevice into which moisture may penetrate and lodge is dangerous. Soft-soldered contacts underground are not to be trusted, especially on track laid in streets, which is sure to be wet with dirty water, though there is no apparent reason why soldered contact entirely above ground should not be durable, if all traces of corrosive flux are removed. Amalgamated steel surfaces are not durable and soon rust in track exposed to dampness. Expanded or compressed terminal bonds, which have not been properly applied, may be loosened by the movement of the rail, and well-soldered bonds may be loosened or torn off by the same means if they are too rigid. No mention has been made of accidental breakage of bonds. Of course, bonds which are improperly located may be knocked off by rolling stock, and various local external conditions may operate to destroy any kind of bond.

Length of Bond. A short rail bond is more economical of copper than a long one, but is more liable to damage from vibration of a loose joint. A short concealed bond should not be used where the rail joint is not rigidly supported. The length of a bond to be concealed between joint plate and rail is, under certain conditions, somewhat dependent upon the spacing of joint bolts. The length of bonds in use varies from 6 to 10 and more inches. The 10-in. bond is in very common use. Electrified steam roads are using bonds 16 to 24 in. long. Long bonds for spanning splice bars on small rails should be about 5 in. longer (formed) than the splice bar, and about 6 in. longer than the splice bar on large rails.

Resistance of Bonded Rail Joint. Neglecting the very unreliable conductivity between rail and rail by way of mechanical joint plates, the resistance of a newly bonded joint may be approximated as follows:

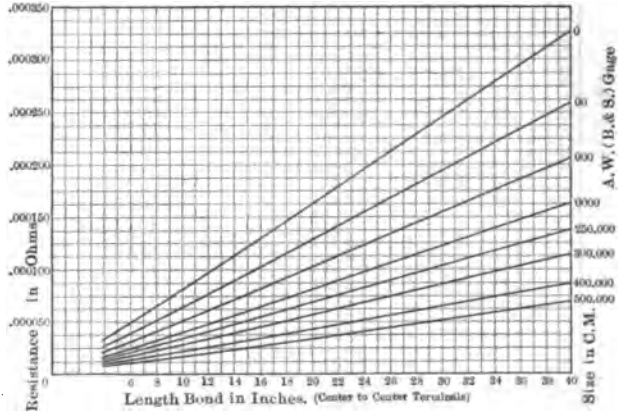


FIG. 54.—Resistance annealed copper rail bonds.

Brazed, Soldered or Welded Bond. Add 1 in. to the length of the bond shank conductor between terminals. The resistance of the bonded joint is approximately equal to the resistance of a length of the shank conductor equal to the length so found.

Compressed or Pin Terminal Bond. To the resistance of a length of shank conductor equal to the length from center to center of terminals measured along the shank conductor add twice the contact resistance of one terminal.

The resistance of the shank conductor may be determined from

RESISTANCE IN INTERNATIONAL OHMS OF A CONTINUOUS STEEL RAIL AT 20° C. OR 68° F., NO JOINTS

Weight of rail, pounds per yard	Ratio of resistance of steel to that of copper									
	8		10		11		12		13	
	1000 ft.	Mile	1000 ft.	Mile	1000 ft.	Mile	1000 ft.	Mile	1000 ft.	Mile
50	0.013243	0.069923	0.016605	0.087674	0.018266	0.096444	0.019925	0.105204	0.021587	0.113979
60	0.011071	0.058455	0.013838	0.073065	0.015221	0.080367	0.016606	0.087680	0.017989	0.094982
70	0.009489	0.050097	0.011861	0.062621	0.013047	0.068888	0.014233	0.075152	0.015419	0.081412
80	0.008303	0.043834	0.010378	0.054796	0.011416	0.060276	0.012454	0.065757	0.013480	0.071174
90	0.007380	0.038966	0.009225	0.048708	0.010147	0.053576	0.011070	0.058449	0.011992	0.063318
100	0.006642	0.035070	0.008302	0.043835	0.009133	0.048222	0.009963	0.052604	0.010794	0.056992
110	0.006039	0.031886	0.007548	0.039853	0.008302	0.043834	0.009057	0.047821	0.009812	0.051807
120	0.005535	0.029224	0.006919	0.036532	0.007611	0.040186	0.008303	0.043839	0.008994	0.047488

AREA OF COPPER IN CIRCULAR MILS EQUIVALENT TO RAILWAY STEEL IN CONDUCTIVITY

Weight of rail, pounds per yard	Actual area in		Ratio of resistance of steel to that of copper				
	Square inches	Circular mils	8	10	11	12	13
50	4.90	6,238,800	779,850	623,880	567,164	519,900	479,908
60	5.88	7,486,600	935,825	748,660	680,600	623,883	575,890
70	6.86	8,734,400	1,091,800	873,440	794,036	727,866	671,876
80	7.84	9,982,100	1,247,763	998,210	907,463	831,841	767,853
90	8.82	11,229,900	1,403,737	1,122,990	1,020,900	935,825	863,838
100	9.80	12,477,700	1,559,712	1,247,770	1,134,336	1,039,812	959,823
110	10.78	13,725,400	1,715,675	1,372,540	1,247,763	1,143,783	1,055,800
120	11.76	14,973,200	1,871,650	1,497,320	1,361,200	1,247,766	1,151,784

Fig. 54. Knowing the thickness of the rail web and diameter of terminal hole in web, the contact area (considering only area of hole wall) may be determined from Fig. 55. For thickness of web see rail dimensions on pp. 46–51. Common outside diameters of bond plugs of compressed or expanded terminal bonds are as follows:

Size of bond, A.W.G. (B. & S.) and cir. mils	Diameter of plug, inches
0	½, ⅝
00	½, ⅝, ¾, ⅞
000	¾, ⅞
0000	¾, ⅞
300,000	1
500,000	1

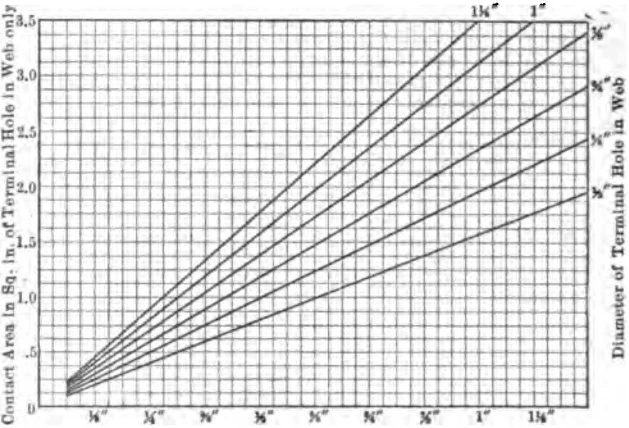


FIG. 55.—Contact area compressed or pin terminal rail bonds.

Tests made by Messrs. Hall, Smith and Starbird at the Worcester Polytechnic Institute indicate that the contact resistance between soft steel and pure copper at pressures from 20,000 to 30,000 lb. per square inch has values from 1/2 to 1 microhm per square inch. These values are plotted in Fig. 56. The contact resistances of bond terminals vary from each other, depending upon the many factors in the process of installation. The value, 0.8 microhm (0.0000008 ohm), may be used in the practical calculation of the resistance of track return where bonds are carefully installed.

Resistance of Track Return. The resistance of a given section of track using both rails as return conductors is equal to one-half the resistance of the sum of all the joints plus one-half the resistance of the rail between joints contained in one of the rails of that section. This may be determined by the following method: From one rail length (ordinarily 30 or 60 ft.) subtract the length of one joint (distance between centers of the terminals of one bond installed), and by the table, page 694 find the resistance of the part of rail remaining (in the absence of more definite information the ratio of resistance of steel to that of copper may be taken as 11 for ordinary running rail). To this, add the resistance of one bonded joint (see Resistance of Bonded Rail Joint, page 693). The resistance of the given section of track will be equal to one-half this sum multiplied by the quotient obtained by dividing the length of the given section by the length of one rail. This may be conveniently expressed as follows:

$$R = \frac{r(l - l_1) + r_1}{2} \times \frac{L}{l}$$

in which R = resistance of section of track, ohms
L = length of section, feet
l = one rail length, feet
l_1 = length of one joint, feet
r = resistance of rail, ohms per foot. See page 694.
r_1 = resistance of one bonded joint, ohms.

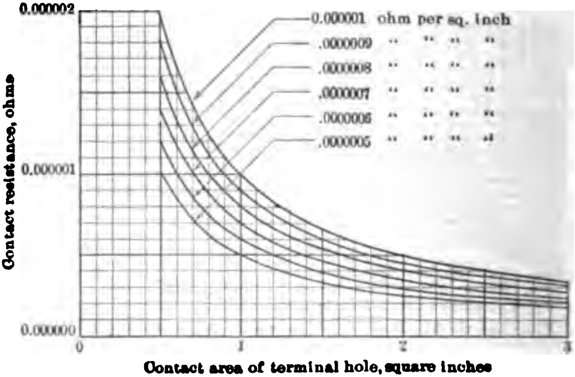


FIG. 56.—Contact resistance.

The allowable value of the resistance, R, depends upon the current flowing and the allowable voltage drop. Its value is determined as follows:

$$R = \frac{e}{I}$$

in which R = the allowable resistance of the given section of track, ohms
e = the allowable voltage drop from one end to the other of the given section, volts
I = current flowing in track return, amperes.

The allowable voltage drop may depend upon the satisfactory operation of apparatus or it may depend upon local regulations or upon the economical amount of power loss. The power loss may be found as follows:

$$p = \frac{eI}{1000}$$

in which p = power lost, kilowatts.

(Significance of remaining symbols as above.)

Size of Bond. A common allowance for the area of cross-section of an ordinary joint bond is 500 cir. mils per ampere carried by the bond. Short bonds may be operated at a much greater current density. The latter is of value in handling rush loads of short duration.

Cross Bonding. In order to maintain the current in the two rails of the track return circuit as nearly equal as possible and to care for a possible open bond, the two running rails should be bonded together by "cross bonds." These make contact at the web of the rail or at the outside of the rail head. The spacing of cross bonds depends upon the density of traffic. In city work it is customary to place them about three per 1000 ft. They are spaced from this to 1500 ft., but commonly 1000 ft. in interurban work. Where track circuit signal systems are used the matter of cross bonding must be considered in its relation to the signal system. Cross bonding may be entirely prohibited or, in the case of alternating current signal systems, it may be provided by inductive bonds (see page 893).

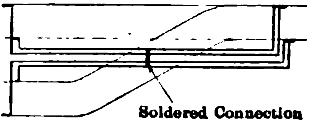


FIG. 57.—Bonding around switch.

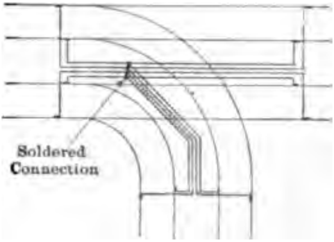


FIG. 58.—Bonding around branch-off.

Bonding at Special Work. Special work must be removed comparatively frequently, its joints are subject to great vibration and offer construction difficulties to bonding, it is of steel having low conductivity, and it contains many joints. Thus, the bonding of joints through special work in a manner similar to that on ordinary track is unreliable. It has been found satisfactory to bond around special work by means of bare stranded copper (500,000 to 1,000,000 cir. mil cable is commonly used for this work). Figs. 57 to 61, inclusive, give schemes for bonding around several typical pieces of special work. It is the practice of many roads to bond through as well as around special work. This is necessary in city work and is done by connecting each piece of rail in the special work to the cable which bonds around

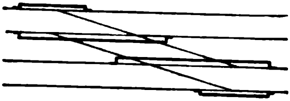


FIG. 59.—Bonding around crossover.

the special work, or by bonding the joints in the special work, as in straight-away track construction. As in the case of cross bonding, where track signal systems are used, bonding at special work should be considered in its relation to the signal system. Much care should be taken to insure good contact at the terminals of cables used in bonding around special work. The following briefly outlines the tests and results of the Chicago Board of Supervising Engineers, 1911, in the determination of the proper method to use in attaching such auxiliary cables:

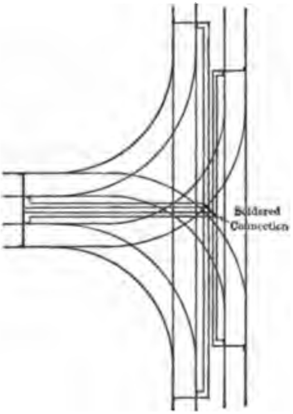


FIG. 60.—Bonding around Y.

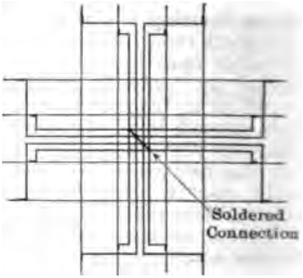


FIG. 61.—Bonding around crossing

The tests comprised five different types of terminals.

First. Welded connection (Fig. 62) in which the weld is made under current of 15,000 amperes to 25,000 amperes applied with flux and spelter and a final compression of about 15 tons.

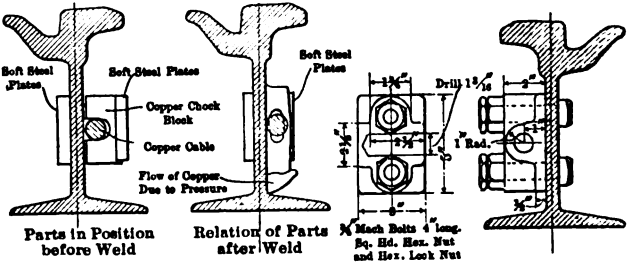

Soft Steel Plates
Soft Steel Plates
Copper Chock Block
Copper Cable
Parts in Position before Weld
Soft Steel Plates
Flow of Copper Due to Pressure
Relation of Parts after Weld
1⅜"
Drill 1 3/16"
2½"
2⅛"
3"
⅞" Mach Bolts 4" long. Sq. Hd. Hex. Nut and Hex. Lock Nut
2"
1"
1" Rad.
⅛"

FIG. 62.—Welded and bolted cable terminals.

Second. The same type of joint with a considerable reduction in the final pressure applied.

Third. Welded connection in which the cable is inclosed by a mold containing an overflow chamber and clamped against the freshly cleaned web of the rail. Especially prepared copper is ured into this mold.

Fourth. Bolted type terminal (Fig. 62) constructed especially for this experimental work and so designed that the thickness of copper and the length of iron bolt are inversely proportional to the expansion coefficients of copper and iron, so that the changes in temperature will not tend to loosen the connection. This type was tested under varying compressions with both increasing and decreasing loads and plain as well as amalgamated surface.

Fifth. A multiple-pin type terminal, which was made up from standard bond terminals.

An analysis of the general results of the tests indicates:

First. A very large improvement in the conductivity—over 50 per cent.—of Type 1, by reducing the final compression as noted under the description of Type 2.

Second. Under a pressure of about 75,000 lb. or 50,000 lb. per square inch the improvement in conductivity practically ceases.

Third. Bolted type terminals show ten to fifteen times greater unit conductivity than either of the welded type terminals and at about one-half the cost per terminal.

Fourth. The cable weld (Fig. 62) showed the greatest mechanical strength—13,200 lb. shear per square inch of contact.

Fifth. A bolted type terminal can be developed which will be suitable for installation in limited numbers, while for a large number of connections the cable weld is most desirable on account of its higher mechanical strength and conductivity at lower cost.

As a result of these tests it was decided to adopt the electrically welded terminal as the standard. This standard is now in force on the lines of the Chicago City and Chicago Railways companies.

Code of Bonding Precautions. To insure proper attention to details essential to proper bonding the bonding department should be provided with a code of bonding precautions. The following is an example of such a code by Mr. Howard H. George, Electric Railway Journal, 1914, for the installation of pin terminal bonds.

1. Every roadmaster and foreman should see that one or more men in each gang are taught the proper way of installing bonds, and should be sure that any bonding done thereafter is performed by these men.

2. When renewing rail or joint plates on single track in operation, care should be taken not to open or disconnect both rails at the same time, as this would open the return circuit by which the current returns from the cars to the power house. When it is absolutely necessary to open both rails, a long copper jumper should be installed to connect the open ends so that the path of the return circuit shall not be interrupted. This applies more particularly to road ends and interurban lines.

3. Whenever any track is opened up and any ground wires for electric lights, lightning arresters, or other electrical apparatus which should be connected to the rail, are found disconnected, they should be reported at once to the bond inspector or distribution department, so that they may be repaired before the track is closed up. This is very important and should receive careful attention.

4. No bond holes should be drilled until just before the bonds are ready to be put in. There are, of course, times when it is desirous to have the holes drilled before the rail is placed on the ties. When this occurs, it is necessary to place a tight-fitting plug in the hole as soon as it is drilled to avoid any possible introduction of moisture. To drill a hole a day or two before and not protect it from moisture means a film of rust in the hole, which will greatly increase the resistance of the joint.

5. Old bonds should never be used again because they become battered up in driving them out. Then, when they are put in again they r make good contact with the rail, which means a poor bond. Where

is removed from the rail it is not advisable to use the same hole in putting in a new bond, unless some precautionary methods are used. The proper way is to drill a new hole, but as this is not allowable in some types of rails ream out the old hole and use a bond with a special large sized terminal.

6. Great care should be taken with the drills used in making bond holes. If an improperly ground drill is used the hole will be irregular and oval shaped, thus giving a poor contact between the terminal and the rail. All dull and broken drills should be carefully boxed, labeled and sent to the shop to be reground, where the company has installed a special machine for the purpose to do the work perfectly and at much less expense than could possibly be done by hand.

7. In drilling bond holes never use oil to lubricate the drills. It is better not to use anything, but where it is absolutely necessary to use a lubricant, nothing more than a soda solution should be employed.

8. Holes, after being drilled, should be carefully cleaned of any chips, and wiped dry of any solution that may have been used to lubricate the drills. The holes must have a smooth and dry surface so that the bond terminal will make a good contact all around.

9. With a proper-sized hole, the bond terminal will make a very snug fit, not small enough to have to be driven with a heavy maul nor large enough to be put in easily with the hands. It should require a couple of taps with a hammer weighing about 3 lb. With a heavy hammer or spike maul, the head of the bond terminal is very likely to be battered, and the taper punch struck on the slant, causing it to split and bend the terminal.

10. After the bond terminals are in position, always drive the long steel taper punch entirely through the terminal, taking care to strike the punch squarely on the head. The small end of this punch should be dipped in some kind of heavy grease, such as track grease, just before it is driven through each terminal. The grease will lubricate the sides of the punch, thereby expanding the terminals and not drawing the copper with the punch.

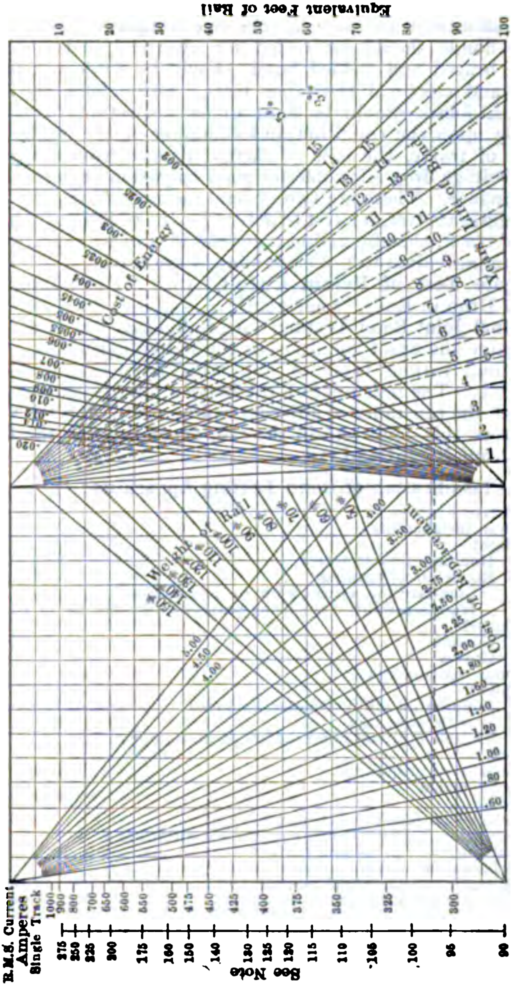
11. Drive into each of the expanded terminals one of the short drift pins, thus expanding the copper a little more. This pin should be driven in until it is just flush with the head of the bond terminal.

12. The bond should then be shaped by straightening out the bond conductors, and forming them so that they will not be cut by either the track bolts or the splice bars. If it is a 36-in. bond, it should be so shaped that it will in no way interfere with the removal of the splice bars.

13. The bond, and particularly the bond terminals on both sides of the rail, are to be painted with some good weatherproof paint, care being taken to see that the paint fills the space back of the terminal heads.

Economic Replacement of Bonds. The length of life of a rail bond in place may be anything up to the length of life of the rails it connects, depending upon the degree of perfection of the installation and the condition and care of track. The life of a bond may terminate at actual breakage or at the point at which its resistance becomes such that the voltage drop becomes too great or the saving of energy brought about by its renewal will justify the total cost of such renewal. The chart, Fig. 63, gives a method of determining the resistance of a bond in terms of feet of adjacent rail at which a bond should be renewed, considering financial economy only. It shows the increase in resistance over that of a well-bonded joint at which the energy saving amortizes the cost of replacement in a given number of years. The use of the chart is explained by the following example, solution of which is shown by the dotted lines on Fig. 63: R.m.s. current in track, 450 amperes; weight of rail, 90 lb. per yard; cost of energy saved, $0.0025 per kw.-hr.; cost of bond renewal, $2.00 per bond; estimated life of bond, 7 years; interest, 5 per cent. Chart shows that joints in this case should be rebonded when resistance is (approximately) 27.6 ft. of rail *more* than resistance of newly bonded joint.

Bond Testing. An inspection to determine the condition of the joint between bond terminal and shank may be made by sectioning the terminals in various planes, polishing the cut surfaces with a



NOTE: If amperes are taken in left-hand column, multiply ft. of rail by ten.

FIG. 63.—Economic replacement resistance of rail bonds.

smooth file, emery, and crocus to remove all burrs, and then etching with a mixture of strong sulphuric and nitric acids, when the defective welds will show as fine black lines, and the actual welds the form of the various component parts of the bond at that surface can be traced by the different colors of the metal after etching.

Bonded Joint Testing. Joints should be tested immediately after installation of bonds. At this time compressed or expanded terminal bonds should be tested for electrical resistance, and soldered, brazed and welded bonds should be subjected to both hammer and electrical resistance tests. Throughout the life of the bonds, joints should be kept under inspection to a degree depending upon the condition and character of the roadbed, the intensity of traffic, the cost of energy, danger from electrolysis, and the voltage drop allowable for good operation or permitted by local ordinance. There are two general methods of testing bonds: one, an aggregate test, is a test to determine the resistance of a whole section of track, thereby giving a general idea of its condition; the other is an individual test of each joint in the track.

Aggregate Test of Return Circuit. (See "Determination of Potential Drop in Rails," page 722.)

Individual Joint Bond Testing. An individual test is necessary to determine the exact condition of the individual bonds. Many methods and various types of apparatus have been devised for such testing. The resistance of the bonded joint is generally compared with the resistance of adjacent rail by comparing the voltage drops across this joint and in the rail, accompanying the flow of current through joint and rail.

General Classification of Bond Testing Apparatus:

- Hand instruments
  - One-man instruments
    - Sight
      - Double millivoltmeters
      - Roller direct reading
        - Standard for returns with 40–50 amperes
        - High sensibility type using battery impressed 10–12 amperes
    - Sound
      - Conant
      - Crown
  - Two-man instruments
    - Sight
      - Differential millivoltmeter, balanced by measuring adjacent rail with steel tape
      - Double millivoltmeter, balanced in same manner
- Test Cars
  - Two classes of propulsion
    - Self-propelled
    - Trailer
  - Two classes current through joints
    - Circulation from low-voltage motor generator set
    - Resistance and propelling current
  - Four classes indication
    - Automatic recording and marking
    - Automatic signaling and marking
    - Automatic signaling and hand marking
    - Indicating and hand marking.

Typical Hand Bond Testing Instruments. The instrument consists essentially of two parts: first, a folding framework fitted with three steel rail contacts 3 ft. apart as shown in Fig. 64; and second, a standard differential voltmeter controlled by a two-point switch (in the circuit through the unjointed rail). As shown in

Fig. 64, the frame is so placed on the rail that the joint is included between two of the terminals with an equal length of solid stock rail between the center and the other outer terminal. If the voltmeter reading indicates a joint conductivity of 100 per cent. or over, this is the only observation required. If less than 100 per cent., the voltmeter is connected up with a detachable prod by which contact is made at successive points along the rail until a balance appears on the differential voltmeter. The conductivity of the joint may be then computed from the relative rail distances included between points. An average of about 200 joints may be tested in a day of 8 hours on a fairly free track, which corresponds to slightly over a mile of single track a day per man.

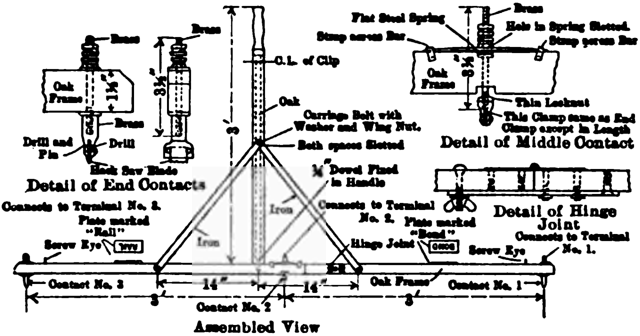


FIG. 64.—Contact frame for hand bond testing.

The scheme of connections of another typical hand bond tester (the Roller Smith) is shown in Fig. 65. It consists of a T-shaped bar, *C*, similar to that shown in Fig. 64, upon which three contacts are mounted, and connected with the electrical

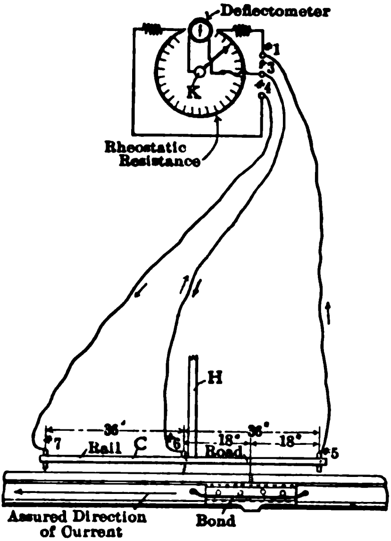


FIG. 65.—Hand bond-testing circuits.

mechanism as shown. The contacts are made of short pieces of hacksaw blades held in clamps. By rocking the handle *H* of the bar at right angles to the rails the blades saw through the dirt and scale on the rails and insure good contacts. The principle of operation is that of the Wheatstone bridge. By turning the handle *K* the resistance of the two legs of the circuit is varied. The indicator attached to the handle *K* moves around a scale which is so graduated as to read directly the resistance of the section containing the bond in terms of the resistance of unbroken rail when the needle deflection is zero.

Bond Test Car. A test car makes possible a rapid and complete report of the entire track by making a continuous record of track condition and location as the car proceeds at a speed of 8 or 10 miles per hour. As a motor-generator set may be carried, its operation may be independent of the current in the track due to ordinary traffic and it may be operated where traffic conditions are such as to make hand bond testing highly difficult or impossible. Tests may be made by it with great rapidity, thus affording knowledge of the true condition and location of bonds of a whole system in a very short time.

Electrolysis

The electrolytic corrosion of earthed metallic conductors proceeds at a rate dependent upon the rate of flow of the current which leaves the metallic conductor for the earth.

Theoretical Rate. With an oxidizing anode the weight of anode corroded by 1 ampere in 1 second is equal to the electro-chemical equivalent of the metal of the anode. The amount of metal (pounds) corroded by 1 ampere in 1 year is equal to the electro-chemical equivalent of the metal (grams) multiplied by 60 × 60 × 24 × 365 × 0.0022046, the latter figure being the conversion factor between grams and pounds. The product of these factors is 69,524, which may be termed the conversion factor between the electro-chemical equivalent of a metal, as usually expressed in grams, and the theoretical amount of such metal, in pounds, which would be corroded by the electrolytic action of 1 ampere in 1 year. The values are as follows:

Metal	Electro-chemical equivalent, grams	Corroded by 1 ampere in 1 year, pounds
Iron (ferrous)	0.0002895	20.1
Lead	0.0010718	74.5

Variations from Theoretical Rate. In a paper on electrolytic corrosion (Trans. A.I.E.E., 1913), McCollum and Logan show results of some very extended studies by the U. S. Bureau of Standards on the variations from the above theoretical rate. Some of their conclusions are as follows, their term "efficiency of corrosion" being based on the above theoretical rate as 100 per cent. They state that the current density has a marked effect on the corrosion of iron in soils, the efficiency of corrosion being in general greater as the current density is lower. In saturated soil the corrosion may vary between 20 and 140 per cent. for a range of current density varying from about 5 to 0.05 milli-amperes per square centimeter. Moisture content has also a marked effect on efficiency of corrosion, it being in general greater with increased moisture content up to saturation of soil. Temperature changes within the limits commonly encountered in general practice have no marked effect on corrosion efficiency, neither has the depth of burial of pipes, other conditions remaining constant. The amount of oxygen present has no appreciable effect on the efficiency of corrosion in the case of iron immersed in liquid electrolyte, but it has a marked effect on the end products of corrosion. If the corrosion is rapid and supply of oxygen small, there will be a preponderance of magnetic oxide, while if the rate of corrosion is low and the supply of oxygen abundant, the ferric oxide will predominate. Owing to the fact that the supply of oxygen around pipes buried in earth is always more or less limited, the character of the oxides formed gives some indication as to the rate of corrosion, and thus indirectly as to the cause of the corrosion if local conditions are properly considered. The efficiency of corrosion was found not to be a function of the voltage, except in so far as the current density may be affected. Voltages as low as 0.1 to 0.6 volt showed practically the same efficiency of corrosion as 5 to 10 volts or higher. Corrosion tests on a large number of different kinds of soil from widely different sources with average moisture content and current density indicated that corrosion efficiency between 50 to 110 per cent. may usually be expected under most practical conditions.

Resistance of Soils. With a given potential difference between two earthed metallic structures, the amount of current which will flow between them is dependent not only on the contact resistance but also upon the resistance of the soil. Relative to the latter, McCollum and Logan state that the resistance of soils varies throughout a very wide range with variations in moisture content, the resistance of the comparatively dry soil being of the order of several hundred times the resistance of the same soil at about saturation. Above saturation increase in moisture content has but little effect on the resistance of the soil. The resistance of the soil varies greatly with temperature within the ordinary range encountered in practice. In the case of the soils tested the resistance at 18 deg. below zero C. was over two hundred times as great as at 18 deg. above zero C. Even at about freezing temperature the resistance will be several times that at summer temperatures. This has an important bearing on the magnitude of the electrolysis trouble that may occur at different seasons and also indicates that where practicable voltage surveys should not be made when extremely low temperatures prevail. These authors give a table of the specific resistance of soils as found in Philadelphia, Washington, St. Louis and elsewhere, showing it to vary between the extremes of 400 ohms per cubic centimeter for a St. Louis blue clay with 26 per cent. moisture, and 2,340,000 ohms per cubic centimeter for Washington air dry red clay with 4 per cent. moisture.

Contact Resistance. Polarization and film resistances at the surface of the pipes may be an important factor in current flow. As soon as an electromotive force is applied to a buried pipe the current flow drops off rapidly with time, especially during the first few minutes, due to the setting up of counter electromotive forces and the formation of film resistances. McCollum and Logan show the effective resistance as a function of time after the application of about 6 volts between two short lengths of cast-iron pipe buried about 12 ft. apart. The initial resistance of about 18 ohms practically doubled within half an hour after the voltage was applied and after that the resistance remained practically constant. In this case the effect of polarization and film resistance was practically as great as the total soil resistance between the pipes.

The character of the electric railway roadbed is an important factor in determining the extent of leakage of stray current into the earth. A well-drained rock or concrete roadbed may in general be expected to offer much higher resistance to the leakage of current than one in which the construction is such that a large amount of moisture is retained.

Electrolysis Tests

Usual Polarities. With the common arrangement of connecting the positive terminal of the railway generator to the trolley and the negative to the rails, the general path of stray currents is from the rails through earth to pipes or cable sheaths at places distant from the power station, through the pipes or cable sheaths and from these through the earth back to the rails or other return conductors in the vicinity of the power station. Where current tends to flow from the rail to a buried pipe or cable sheath the rail has a positive potential with reference to the buried conductor which is negative. This is generally known as the negative district. Where current tends to flow from a buried conductor to the rail

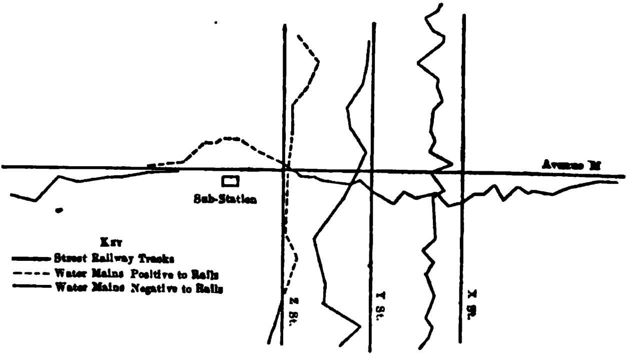


FIG. 66.—Sample potential survey.

the buried conductor has a positive potential with reference to the rail, and this is usually known as the positive district. The intermediate district where the potentials may shift from positive to negative is sometimes called the neutral district.

Potential Survey. As the polarity of the earthed conductor is indicative of the tendency of current to flow, and electrolytic corrosion only takes place where current leaves the current conductor for earth, the first set of tests is generally a set of potential readings and is called potential survey. It is permissible and the usual practice to use hydrants or service connections for a contact to underground piping system. These readings are usually made with a low-reading voltmeter, preferably with the zero indication in the center of the scale, and readings are taken in a large number of places throughout the system between the rails and the buried conductors (pipes or cable sheaths). The voltmeter used should preferably have a high resistance to minimize the effect of accidental poor contact. A Weston high resistance zero center voltmeter with ranges of 1.5, 15 and 150 volts is a very satisfactory instrument. Readings should be taken at intervals of a few seconds for several minutes at each point and notation made of the location and of the maximum, minimum and average readings. It is desirable to plot these potential readings graphically on a map similar to Fig. 66, where the differences of potential between city water mains and street railway tracks are shown graphically plotted with the latter as a base line. It is also desirable to show on this map the size and location of the various pipe systems. A more detailed map of this character is shown in Fig. 67 which is an actual potential survey in the Grand Avenue substation district of the Chicago Railways Company. This figure is reproduced from the Fourth Annual Report of the Board of Supervising Engineers, Chicago Traction.

Potential Readings Merely Indicative. It should be remembered always that the potential difference between pipes and rails, even if large, is not conclusive evidence of stray currents, but is only an indication of the points at which current may be flowing from rails to pipes or from pipes to rails or between other conductors. In fact, a high potential reading is generally an indication of high earth resistance and consequently a small current flow rather than of a large current flow.

Direction and Relative Magnitude of Current Flow in Underground Conductors. Tests to determine the direction of current flow in underground conductors may be made by measuring potential differences between two points in the underground conductor. A zero center Weston milli-voltmeter with scales of 10 and 100 millivolts is a satisfactory instrument for this test and connections may be made to the cable sheath in two adjacent manholes or on the piping system between hydrants or service connections 100 or 200 ft. apart. These readings which are clearly indicative of the direction of current flow may be used in the calculation of the amount of current flow in the case of cable sheaths where the resistance per foot can be quite accurately known and is not seriously affected by joint resistances. In the case of pipes, however, such readings can only be used as an indication of the rela

TABLE FOR DETERMINATION OF CURRENT FLOW ON PIPI FROM MILLIVOLT DROP ALONG CONTINUOUS LENGTH OF PIPE BETWEEN JOINTS

L = Distance between contacts in feet
E = Instrument reading in millivolts
K = Constant from table
$\frac{KE}{L}$ = Current flow in amperes.

STANDARD CAST-IRON PIPE
(Based on Resistance of 0.00144 ohm per lb.-ft.)

Classification					Actual dimensions		Weight per ft. exclusive of hub—lb.	K—current for one millivolt drop per foot of continuous pipe—amperes
Nominal diameter, inches	*Association standard	Class letter †	Head, feet	Pressure, lb. per sq. in.	Outside diameter, inches	Inside diameter, inches		
4	N	A			4.80	4.12	14.9	10.3
4	N	C			4.80	4.08	15.7	10.9
4	N	E			4.80	4.02	16.9	11.7
4	G				4.80	4.00	17.2	12.0
4	W	A	100	43	4.80	3.96	18.0	12.5
4	N	G			5.00	4.16	18.9	13.1
4	N	I			5.00	4.10	20.0	13.9
4	W	B	200	86	5.00	4.10	20.0	13.9
4	N	K			5.00	4.04	21.3	14.8
4	W	C	300	130	5.00	4.04	21.3	14.8
4	W	D	400	173	5.00	3.96	22.8	15.8
6	N	A			6.90	6.14	24.3	16.9
6	N	C			6.90	6.06	26.7	18.5
6	G				6.90	6.04	27.2	18.9
6	W	A	100	43	6.90	6.02	27.8	19.3
6	N	E			6.90	5.98	29.1	20.2
6	W	B	200	86	7.10	6.14	31.1	21.6
6	N	G			7.10	6.10	32.4	22.5
6	W	C	300	130	7.10	6.08	32.9	22.8
6	N	I			7.10	6.02	34.8	24.2
6	W	D	400	173	7.10	6.00	35.3	24.5
6	W	E	500	217	7.22	6.06	37.7	26.2
6	W	F	600	260	7.22	6.00	39.6	27.4
6	W	G	700	304	7.38	6.08	42.8	29.7
6	W	H	800	347	7.38	6.00	45.2	31.4
8	N	A			9.05	8.21	35.5	24.7
8	G				9.05	8.15	37.9	26.3
8	W	A	100	43	9.05	8.13	38.7	26.9
8	N	C			9.05	8.09	40.3	28.0
8	W	B	200	86	9.05	8.03	42.7	29.6
8	N	E			9.05	7.99	44.3	30.7

* W = American Water Works Association Standard
N = New England Water Works Association Standard
G = American Gas Institute Standard.

† As used by the American Water Works Association and the New England Works Association.

STANDARD CAST-IRON PIPE.—*Continued*

(Based on Resistance of 0.00144 ohm per lb.-ft.)

Classification					Actual dimensions		Weight per ft. exclusive of hub—lb.	K-current for one millivolt drop per foot of continuous pipe—amperes
Nominal diameter, inches	*Association standard	Class letter †	Head, feet	Pressure, lb. per sq. in.	Outside diameter, inches	Inside diameter, inches		
8	W	C	300	130	9.30	8.18	47.9	33.3
8	N	G	......	....	9.30	8.14	49.6	34.5
8	W	D	400	173	9.30	8.10	51.2	35.5
8	N	I	......	....	9.30	8.04	53.6	37.2
8	W	E	500	217	9.42	8.10	56.7	39.4
8	W	F	600	260	9.42	8.00	60.6	42.1
8	W	G	700	304	9.60	8.10	65.0	45.1
8	W	H	800	347	9.60	8.00	69.0	48.0
10	N	A	......	....	11.10	10.16	49.0	34.0
10	G	......	......	....	11.10	10.12	51.0	35.4
10	N	B	......	....	11.10	10.10	51.9	36.1
10	W	A	100	43	11.10	10.10	51.9	36.1
10	N	C	......	....	11.10	10.04	54.9	38.1
10	N	D	......	....	11.10	9.98	57.9	40.2
10	W	B	200	86	11.10	9.96	58.9	40.9
10	N	E	......	....	11.40	10.20	63.6	44.1
10	W	C	300	130	11.40	10.16	65.5	45.5
10	N	F	......	....	11.40	10.14	66.5	46.2
10	N	G	......	....	11.40	10.06	70.5	49.0
10	W	D	400	173	11.40	10.04	71.5	49.7
10	N	H	......	....	11.40	10.00	73.5	51.1
10	W	E	500	217	11.60	10.12	78.7	54.6
10	W	F	600	260	11.60	10.00	84.6	58.8
10	W	G	700	304	11.84	10.12	92.4	64.1
10	W	H	800	347	11.84	10.00	98.5	68.4
12	N	A	......	....	13.20	12.22	61.1	42.5
12	N	B	......	....	13.20	12.14	65.9	45.7
12	G	......	......	....	13.20	12.12	67.0	46.5
12	W	A	100	43	13.20	12.12	67.0	46.5
12	N	C	......	....	13.20	12.06	70.6	49.0
12	N	D	......	....	13.20	11.98	75.3	52.3
12	W	B	200	86	13.20	11.96	76.4	53.0
12	N	E	......	....	13.50	12.20	81.9	56.8
12	W	C	300	130	13.50	12.14	85.5	59.4
12	N	F	......	....	13.50	12.12	86.6	60.2
12	N	G	......	....	13.50	12.04	91.5	63.6
12	W	D	400	173	13.50	12.00	93.8	65.1
12	N	H	......	....	13.50	11.96	96.2	66.8
12	W	E	500	217	13.78	12.14	104.0	72.3
12	W	F	600	260	13.78	12.00	112.0	77.9

See footnotes, page 710.

STANDARD CAST-IRON PIPE.—*Continued*

(Based on Resistance of 0.00144 ohm per lb.-ft.)

Classification					Actual dimensions		Weight per ft. exclusive of hub—lb.	K-current for one millivolt drop per foot of continuous pipe—amperes
Nominal diameter, inches	*Association standard	Class letter †	Head, feet	Pressure, lb. per sq. in.	Outside diameter, inches	Inside diameter, inches		
12	W	G	700	304	14.08	12.14	125.	86.7
12	W	H	800	347	14.08	12.00	133.	92.4
14	N	A	......	....	15.30	14.24	76.8	53.4
14	N	B	......	....	15.30	14.16	82.3	57.1
14	W	A	100	43	15.30	14.16	82.3	57.1
14	N	C	......	....	15.30	14.08	87.9	61.0
14	N	D	......	....	15.30	13.98	94.8	65.8
14	W	B	200	86	15.30	13.98	94.8	65.8
14	N	E	......	....	15.65	14.25	103.	71.4
14	W	C	300	130	15.65	14.17	108.	75.0
14	N	F	......	....	15.65	14.15	109.	76.2
14	N	G	......	....	15.65	14.07	115.	80.0
14	W	D	400	173	15.65	14.01	119.	82.8
14	N	H	......	....	15.65	13.99	121.	83.9
14	W	E	500	217	15.98	14.18	133.	92.4
14	W	F	600	260	15.98	14.00	145.	101.
14	W	G	700	304	16.32	14.18	160.	111.
14	W	H	800	347	16.32	14.00	172.	120.
16	N	A	......	....	17.40	16.30	90.9	63.1
16	N	B	......	....	17.40	16.20	98.9	68.6
16	W	A	100	43	17.40	16.20	98.9	68.6
16	G	.....	......	....	17.40	16.16	102.	70.7
16	N	C	......	....	17.40	16.10	107.	74.1
16	N	D	......	....	17.40	16.00	115.	79.6
16	W	B	200	86	17.40	16.00	115.	79.6
16	N	E	......	....	17.80	16.30	125.	87.1
16	N	F	......	....	17.80	16.20	133.	92.6
16	W	C	300	130	17.80	16.20	133.	92.6
16	N	G	......	....	17.80	16.10	141.	98.2
16	W	D	400	173	17.80	16.02	147.	102.3
16	N	H	......	....	17.80	16.00	149.	103.5
16	W	E	500	217	18.16	16.20	165.	114.5
16	W	F	600	260	18.16	16.00	181.	125.5
16	W	G	700	304	18.54	16.18	201.	139.5
16	W	H	800	347	18.54	16.00	215.	149.0
18	N	A	......	....	19.25	18.11	104.	72.5
18	N	B	......	....	19.25	17.99	115.	79.8
18	W	A	100	43	19.50	18.22	118.	82.2
18	N	C	......	....	19.50	18.12	127.	88.5
18	N	D	......	....	19.50	18.00	138.	95.8
18	W	B	200	86	19.50	18.00	138.	95.8

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STANDARD CAST-IRON PIPE.—*Continued*
(Based on Resistance of 0.00144 ohm per lb.-ft.)

Classification					Actual dimensions		Weight per ft. exclusive of hub—lb.	K-current for one millivolt drop per foot of continuous pipe—amperes
Nominal diameter, inches	*Association standard	Class letter †	Head, feet	Pressure, lb. per sq. in.	Outside diameter, inches	Inside diameter, inches		
18	N	E	......	....	19.70	18.10	148.	103.
18	N	F	......	....	19.70	17.98	159.	110.4
18	W	C	300	130	19.92	18.18	162.	113.
18	W	D	400	173	19.92	18.00	178.	123.8
18	W	E	500	217	20.34	18.20	202.	140.5
18	W	F	600	260	20.34	18.00	220.	152.6
18	W	G	700	304	20.78	18.22	245.	170.
18	W	H	800	347	20.78	18.00	264.	183.3
20	N	A	......	....	21.30	20.10	122.	84.6
20	N	B	......	....	21.30	19.98	134.	93
20	W	A	100	43	21.60	20.26	137.	95.4
20	G	......	......	....	21.60	20.24	140.	97.0
20	N	C	......	....	21.60	20.16	147.	102.5
20	N	D	......	....	21.60	20.02	161.	112.
20	W	B	200	86	21.60	20.00	163.	113.
20	N	E	......	....	21.90	20.20	175.	122.
20	N	F	......	....	21.90	20.06	189..	131.
20	W	C	300	130	22.06	20.22	191.	132.
20	W	D	400	173	22.06	20.00	212.	148.
20	W	E	500	217	22.54	20.24	241.	167.
20	W	F	600	260	22.54	20.00	265.	184.
20	W	G	700	304	23.02	20.24	295.	205.
20	W	H	800	347	23.02	20.00	319.	221.
24	N	A	......	....	25.40	24.12	156.	108.
24	N	B	......	....	25.40	23.96	174.	121.
24	G	......	......	....	25.80	24.28	187.	130.
24	W	A	100	43	25.80	24.28	187.	130.
24	N	C	......	....	25.80	24.20	196.	136.
24	N	D	......	....	25.80	24.04	215.	149.
24	W	B	200	86	25.80	24.02	217.	151.
24	N	E	......	....	26.10	24.20	234.	163.
24	N	F	......	....	26.10	24.04	253.	176.
24	W	C	300	130	26.32	24.24	258.	179.
24	W	D	400	173	26.32	24.00	286.	198.
24	W	E	500	217	26.90	24.28	328.	228.
24	W	F	600	260	26.90	24.00	362.	251.
30	N	A	......	....	31.60	30.18	215.	149.
30	N	B	......	....	31.60	29.98	245.	170.
30	G	......	......	....	31.74	30.04	257.	179.

See footnotes, page 710.

STANDARD CAST-IRON PIPE.—*Continued*
(Based on Resistance of 0.00144 ohm per lb.-ft.)

Classification					Actual dimensions		Weight per ft. exclusive of hub—lb.	K-current for one millivolt drop per foot of continuous pipe—amperes
Nominal diameter, inches	*Association standard	Class letter †	Head, feet	Pressure, lb. per sq. in.	Outside diameter, inches	Inside diameter, inches		
30	W	A	100	43	31.74	29.98	266.	185.
30	N	C	......	....	32.00	30.18	277.	192.
30	N	D	......	....	32.00	29.98	306.	213.
30	W	B	200	86	32.00	29.94	312.	217.
30	N	E	......	....	32.40	30.20	337.	234.
30	N	F	......	....	32.40	30.00	367.	255.
30	W	C	300	130	32.40	30.00	367.	255.
30	W	D	400	173	32.74	30.00	422.	292.
30	W	E	500	217	33.10	30.00	479.	333.
30	W	F	600	260	33.46	30.00	537.	373.
36	N	A	......	....	37.80	36.22	287.	199.
36	N	B	......	....	37.80	36.00	326.	226.
36	G	......	......	....	37.96	36.06	345.	239.
36	W	A	100	43	37.96	35.98	358.	248.
36	N	C	......	....	38.30	36.26	373.	259.
36	N	D	......	....	38.30	36.04	412.	286.
36	W	B	200	86	38.30	36.00	418.	290.
36	N	E	......	....	38.70	36.20	459.	319.
36	W	C	300	130	38.70	35.98	497.	346.
36	N	F	......	....	38.70	35.96	502.	349.
36	W	D	400	173	39.16	36.00	581.	404.
36	W	E	500	217	39.60	36.00	666.	463.
36	W	F	600	260	40.04	36.00	753.	523.
42	N	A	......	....	44.00	42.26	368.	256.
42	N	B	......	....	44.00	42.00	422.	293.
42	G	......	......	....	44.20	42.06	452.	314.
42	W	A	100	43	44.20	42.00	465.	323.
42	N	C	......	....	44.50	42.24	480.	333.
42	N	D	......	....	44.50	41.96	538.	374.
42	W	B	200	86	44.50	41.94	542.	376.
42	N	E	......	....	45.10	42.30	600.	416.
42	N	F	......	....	45.10	42.04	654.	454.
42	W	C	300	130	45.10	42.02	657.	456.
42	W	D	400	173	45.58	42.02	763.	530.
48	N	A	......	....	50.20	48.30	459.	319.
48	N	B	......	....	50.20	48.00	529.	367.
48	N	C	......	....	50.80	48.30	608.	422.
48	G	......	......	....	50.50	47.98	608.	422.
48	W	A	100	43	50.50	47.98	608.	422.
48	N	D	......	....	50.80	48.00	678.	471.

See footnotes, page 710.

STANDARD CAST-IRON PIPE.—*Continued*

(Based on Resistance of 0.00144 ohm per lb.-ft.)

Classification					Actual dimensions		Weight per ft. exclusive of hub—lb.	K-current for one millivolt drop per foot of continuous pipe—amperes
Nominal diameter, inches	*Association standard	Class letter †	Head, feet	Pressure, lb. per sq. in.	Outside diameter, inches	Inside diameter, inches		
48	W	B	200	86	50.80	47.96	686.	477.
48	N	E	......	....	51.40	48.30	757.	526.
48	N	F	......	....	51.40	48.00	828.	575.
48	W	C	300	130	51.40	47.98	832.	578.
48	W	D	400	173	51.98	48.06	961.	667.
54	N	A	......	....	56.40	54.34	559.	388
54	N	B	......	....	56.40	54.00	650.	452.
54	W	A	100	43	56.66	53.96	731.	508.
54	N	C	......	....	57.10	54.36	750.	521.
54	N	D	......	....	57.10	54.02	840.	583.
54	W	B	200	86	57.10	54.00	845.	586.
54	N	E	......	....	57.80	54.26	946.	657.
54	N	F	......	....	57.80	54.00	1041.	723.
54	W	C	300	130	57.80	54.00	1041.	723.
54	W	D	400	173	58.40	53.94	1230.	854.
60	N	A	......	....	62.60	60.40	664.	460.
60	N	B	......	....	62.60	60.00	782.	543.
60	W	A	100	43	62.80	60.02	836.	581.
60	N	C	......	....	63.40	60.40	910.	632.
60	W	B	200	86	63.40	60.06	1010.	701.
60	N	D	......	....	63.40	60.00	1028.	714.
60	N	E	......	....	64.20	60.40	1160.	806.
60	W	C	300	130	64.20	60.20	1220.	848.
60	N	F	......	....	64.20	60.00	1280.	889.
60	W	D	400	173	64.82	60.06	1455.	1010.
72	W	A	100	43	75.34	72.08	1178.	819.
72	W	B	200	86	76.00	72.10	1415.	983.
72	W	C	300	130	76.88	72.10	1745.	1212.
84	W	A	100	43	87.54	84.10	1445.	1005.
84	W	B	200	86	88.54	84.10	1878.	1304.

See footnotes, page 710.

STANDARD STEEL (OR WROUGHT-IRON) PIPE

(Based on resistance of steel—0.00021 ohm per lb.-ft. Based o resistance of wrought iron—0.000181 ohm per lb.-ft.)

Nominal diameter—inches	*Classification	Actual dimensions		Weight per foot. Plain ends—steel—lb.	K-current for one millivol drop per foot continuous pipe—amperes	
		Outside diameter—inches	Inside diameter—inches		Steel	Wrought iron
⅛..........	S	0.405	0.269	0.244	1.16	1.32
⅛..........	X	0.405	0.215	0.314	1.50	1.78
¼..........	S	0.540	0.364	0.424	2.02	2.30
¼..........	X	0.540	0.302	0.535	2.55	2.90
⅜..........	S	0.675	0.493	0.567	2.70	3.07
⅜..........	X	0.675	0.423	0.738	3.51	4.00
½..........	S	0.840	0.622	0.850	4.05	4.60
½..........	X	0.840	0.546	1.09	5.18	5.88
½..........	XX	0.840	0.252	1.71	8.16	9.28
¾..........	S	1.050	0.824	1.13	5.38	6.11
¾..........	X	1.050	0.742	1.47	7.03	7.95
¾..........	XX	1.050	0.434	2.44	11.6	13.2
1..........	S	1.315	1.049	1.68	7.99	9.09
1..........	X	1.315	0.957	2.17	10.3	11.8
1..........	XX	1.315	0.599	3.66	17.4	19.8
1¼.........	S	1.660	1.380	2.27	10.8	12.3
1¼.........	X	1.660	1.278	3.00	14.3	16.2
1¼.........	XX	1.660	0.896	5.21	24.8	28.2
1½.........	S	1.900	1.610	2.72	12.9	14.7
1½.........	X	1.900	1.500	3.63	17.3	19.6
1½.........	XX	1.900	1.100	6.41	30.5	34.7
2..........	S	2.375	2.067	3.65	17.4	19.8
2..........	X	2.375	1.939	5.02	23.9	27.2
2..........	XX	2.375	1.503	9.03	43.0	48.8
2½.........	S	2.875	2.469	5.79	27.6	31.4
2½.........	X	2.875	2.323	7.66	36.5	41.5
2½.........	XX	2.875	1.771	13.69	65.2	74.2
3..........	S	3.500	3.068	7.57	36.0	41.0
3..........	X	3.500	2.900	10.2	48.8	55.6
3..........	XX	3.500	2.300	18.6	88.5	101.
3½.........	S	4.000	3.548	9.11	43.4	49.3
3½.........	X	4.000	3.364	12.5	59.6	67.8
3½.........	XX	4.000	2.728	22.8	109.	124.
4..........	S	4.500	4.026	10.8	51.4	58.4
4..........	X	4.500	3.826	15.0	71.3	81.1
4..........	XX	4.500	3.152	27.5	131.	149.

*S = Standard pipe.
X = Extra strong pipe.
XX = Double extra strong pipe.

STANDARD STEEL (OR WROUGHT-IRON) PIPE.—*Concluded*

(Based on resistance of steel—0.00021 ohm per lb.-ft. Based on resistance of wrought iron—0.000181 ohm per lb.-ft.)

Nominal diameter—inches	*Classification	Actual dimensions		Weight per foot. Plain ends—steel—lb.	K-current for one millivolt drop per foot of continuous pipe—amperes	
		Outside diameter—inches	Inside diameter—inches		Steel	Wrought iron
4½	S	5.000	4.506	12.5	59.8	67.9
4½	X	5.000	4.290	17.6	83.9	95.3
4½	XX	5.000	3.580	32.5	155.	176.
5	S	5.563	5.047	14.6	69.7	79.2
5	X	5.563	4.813	20.8	98.9	112.
5	XX	5.563	4.063	38.5	183.	209.
6	S	6.625	6.065	19.0	90.3	103.
6	X	6.625	5.761	28.6	136.	155.
6	XX	6.625	4.897	53.2	253.	288.
7	S	7.625	7.023	23.5	112.	127.
7	X	7.625	6.625	38.0	181.	206.
7	XX	7.625	5.875	63.1	300.	342.
8	S	8.625	8.071	24.7	118.	134.
8	S	8.625	7.981	28.5	136.	155.
8	X	8.625	7.625	43.4	206.	235.
8	XX	8.625	6.875	72.4	345.	392.
9	S	9.625	8.941	33.9	161.	184.
9	X	9.625	8.625	48.7	232.	264.
10	S	10.750	10.192	31.2	149.	169.
10	S	10.750	10.136	34.2	163.	185.
10	S	10.750	10.020	40.5	192.	219.
10	X	10.750	9.750	54.7	261.	297.
11	S	11.750	11.000	45.6	217.	247.
11	X	11.750	10.750	60.1	286.	326.
12	S	12.750	12.090	43.8	208.	237.
12	S	12.750	12.000	49.6	236.	269.
12	X	12.750	11.750	65.4	311.	354.
13	S	14.000	13.250	54.6	260.	296.
13	X	14.000	13.000	72.1	343.	391.
	S	15.000	14.250	58.6	279.	317.
	X	15.000	14.000	77.4	369.	420.
	S	16.000	15.250	62.6	298.	339.
	X	16.000	15.000	82.8	394.	449.

*S = Standard pipe.
X = Extra strong pipe.
XX = Double extra strong pipe.

which an unknown current *I* is flowing as shown; at first let it be supposed that this current is steady, and of course a direct current. Let *D* be a sensitive galvanometer, milli-voltmeter or any other form of detector of small differences of potential, connected as shown; there should preferably be no variable resistance like an unbonded pipe joint between the two contact points. Let *A* be an ammeter, *B* a few cells of storage battery and *R* an adjustable resistance; the shunt circuit containing them is connected as shown anywhere outside of the points of application of the voltage detector, the farther away the better—they may even be on the other side of a joint. To find the current flowing in the pipe adjust the resistance *R* until *D* reads zero; then there will no longer be any current flowing in the shunted part of the pipe, hence the reading of the ammeter will give the current *I* in the pipe. The current may be said to have been sucked out of the pipe by the battery, and made to flow through the ammeter, where it can be measured; as far as the current in that short section is concerned, the pipe circuit has in effect been electrically cut in two as though an insulating joint had been introduced. If *D* is a galvanometer with proportionate deflections, instead of a mere detector, then by taking a deflection immediately after the shunt circuit has been opened a reading proportionate to the drop of voltage for that current will be obtained. The instrument *D* is thereby calibrated to read the pipe currents directly and can be used for this purpose thereafter; the test with the battery current is therefore merely of the nature of a preliminary calibration and need be carried out only once for each station. If in addition this voltage instrument is calibrated to read directly in volts (usually in terms of milli- or microvolts as for instance a milli-voltmeter) then if the deflection reduced to millivolts is divided by the current it will give the resistance of the pipe in milliohms between the two points of application of the voltmeter, hence it enables the true resistance of the pipe to be measured.

In this method shown in Fig. 68 there should be no current leaving or entering the pipe between the points of application of the shunt, hence the hole should be free from water and there should be no moist earth in contact with that part of the pipe. It is assumed in this method that the short length of pipe between the shunt contacts is too small a fraction of the whole circuit of the pipe line currents to alter these currents when that section is practically cut out of circuit, as it is when the current flows through the shunt. This assumption is probably absolutely safe in all cases in practice. As this method is not in any way concerned with the nature of the circuit beyond the single pipe length under test, nor with the rest of the path of the current, it can be applied to the most complex network of pipes, even when the pipes are interconnected elsewhere or bonded to the track. In measuring the pipe resistance by this method, or in general when the voltage drop is measured, it is of course assumed that the current is constant while the two successive readings are taken, hence it is recommended to repeat the two readings a number of times.

The above applies to steady currents or to such as are steady long enough (a few seconds) to take two successive readings, as the voltage drop and the current cannot be measured simultaneously in the form shown in Fig. 68. In practice such stray currents are likely to vary continuously and often very rapidly. By waiting for a suitable opportunity when the current is practically constant for a short time, measurements of sufficient accuracy can often be made, and as this part of the test is only for the calibration, hence of a preliminary nature and needing to be made only once for each station, one is justified in taking more time for it. When, however, the fluctuations are too rapid, the following modification can be used; it proves to be very satisfactory in practice, although somewhat more cumbersome and requiring additional apparatus, though no more observers.

Let the left hand side of Fig. 69 represent the same arrangement as in Fig. 68. A second voltage detector *D* is then added as shown; it may be a sensitive galvanometer and need not be calibrated. *S* is a second shunt circuit containing a battery and an adjustable resistance which is operated by the observer of *D*, who keeps adjusting it continuously so as to maintain the deflection in *D* constant. During that time the current will be steady for the other observer, who then completes a set of readings with the other instrument *V* according to the method shown in Fig. 68. The purpose of the additional shunt *S* is to take up all the excess of the pipe current above a certain amount, thus acting as a sort of overflow, taking care of the peaks only. The observer of *D* must, therefore, use some judgment in selecting the deflection at which the current is to be held constant; it should be kept at about the base of the average peaks, but should not be too low for the other observer to get good readings for his calibration. It may be a different deflection for each set of readings of the other observer; the only important point is that the current should be held constant in that length of pipe for a long enough time to take two successive readings, requiring only a few seconds.

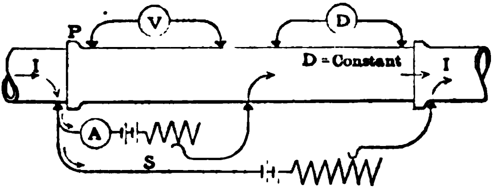


FIG. 69.—Determination of current flow in pipes.

Or, if practicable, the observer of *D* could shunt off the whole pipe current, thus making *D* read zero, and leaving the pipe entirely free from current for the other observer to make his calibration or any other test for which it is required to have the pipe free from current. The adjustable resistance for this extra shunt *S* should be made of a pile of carbon plates which are compressed by means of a lever so that the observer of *D* may quickly follow the variations of the current with it. Very good results can be obtained with such an arrangement after a little practice. As the observer of *D* knows whether or not the current has been successfully kept constant he can discard the readings of the other observer for which the current has not been constant. By taking the mean of a number of good readings, very satisfactory results can be obtained.

Mr. C. W. Kinney, Electric Journal, 1909, describes an approximate method of determining the amount of current flow in a pipe, the resistance of which was not known. The determination was made as follows: The water pipe was exposed for about 6 ft. of its length. Three places on the pipe, 2½ ft. apart, were filed bright and the drop in voltage, as indicated by the voltmeter, between the first and second points and then between the second and third points, was noted. After these readings had been taken, an ammeter reading was taken between the rail and the middle point on the water pipe. While the ammeter was still connected, voltmeter readings were taken as before. The voltage drop between points 1 and 2 showed less than one-half of 1 per cent. of the original value. Thus, the voltage drop between points 2 and 3 could be assumed to be due entirely to the current flowing through the ammeter. The normal flow of current in the pipe was then calculated by a simple proportion; that is, the current flow during the first test bore the same relation to the ammeter reading that the voltmeter deflection between points 2 and 3 during the first test bore to the deflection of the voltmeter needle when the ammeter was connected, since the voltmeter was of uniform scale type. It was, therefore, not necessary to determine the actual value of the divisions on the voltmeter scale in order to find the amount of current flowing in the pipe.

Resistance of and Current in Lead and Lead Alloy Pipes and Sheaths. The resistance of "lead" pipe and "lead" cable sheath will depend upon the alloy that is used in its construction. Practical results indicate that the resistance of pure lead is about 480 microhms (0.00048 ohms) per pound-foot, and the resistance of "lead" cable sheathing containing 3 per cent. tin is about 530 microhms (0.00053 ohms) per pound-foot. The curve sheet, Fig. 70 is arranged for the rapid approximation of resistance and current per millivolt drop per foot for lead and lead-tin alloy pipes. The following example will illustrate the method of using these curves:

What is the resistance per foot of sheath and the current per millivolt drop per foot along a cable sheath of a lead-tin alloy containing 3 per cent. of tin, the resistance of the sheath being 0.00053 ohms per pound-foot? The outside diameter of the sheath is 2.28 in. and the thickness of the wall is 5/32 in.

Starting at the "2.28" point on the "Outside Diameter—Inches" scale (Fig. 70), follow the vertical to intersection with the oblique 0.156 (= decimal equivalent of 5/32) "Thickness—Inches" line. From this point follow the horizontal to the intersection with the "Weight per foot—Lead—3 per cent. Tin-pound" scale at the

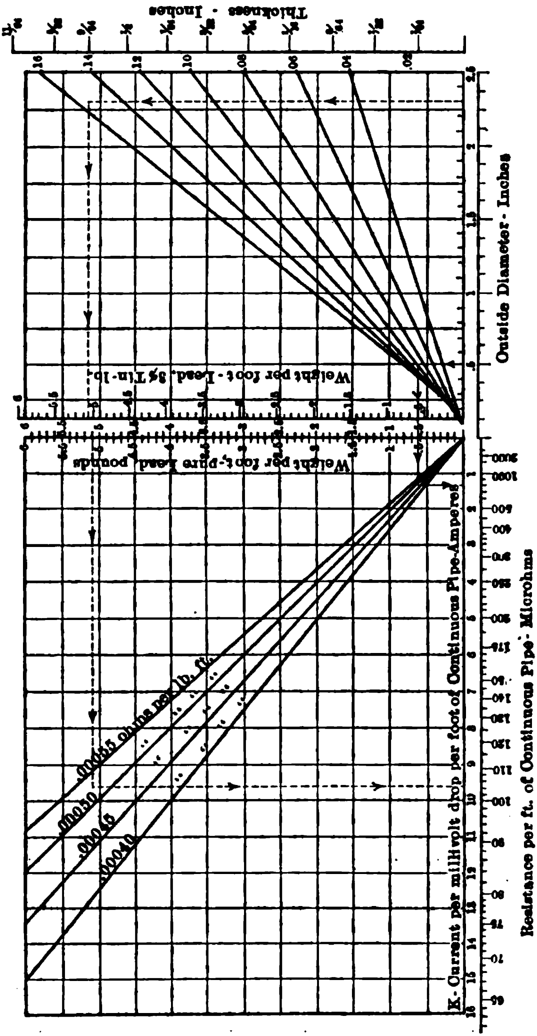


FIG. 70.—Current and resistance, lead and lead alloy cable sheath and pipe.

5.07 lb. point. Now starting with the 5.07 lb. point on the "Weight per foot, pure lead, pounds," follow the horizontal to the left to the intersection with the 0.00053 "ohms per pound-foot" oblique. From this point drop a perpendicular. The intersections of this perpendicular with the horizontal scale indicate that the resistance of the sheath is about 104 microhms per foot and the current is about 9.6 amperes per millivolt drop per foot along the sheath. NOTE: If the cable sheath or pipe is of pure lead, the horizontal should be carried straight through, instead of making the correction on the vertical scale. Such a case is shown by the arrows starting at 0.5 in. outside diameter, Fig. 70.

Determination of Amount and Distribution of Current Leaving Underground Metallic Conductors. The generally accepted method consists in determining the amount of current flow (by one of the methods outlined above) in two locations on the same line of underground pipe. The difference in the amount of current on the pipe between these two locations will then be the amount of current leaving (or entering) the pipe between the two locations.

Determination of Drop of Potential on Rails. As the difference of potential between two points on the rails of an electric railway system is in a way a measure of the tendency to cause stray earth currents, and as many municipal and other public requirements are based on this figure, this test is an important one, but not difficult to make, the essential matter being that of getting a potential wire between the two points on the rail and then measuring the drop with an ordinary voltmeter. Where the company has telephone or signal circuits which may be temporarily disconnected these are often used for this purpose. In some cases a trolley feeder is used, but a spare feeder it not often available during the time when such tests are to be made. Often it is possible to arrange with the local telephone company for its cooperation in furnishing spare wires from a terminal box in one location through proper connections at the telephone exchange to a terminal box in another location, and from these terminal boxes a continuation of the potential wire may be run to the voltmeter and rail. In using such circuits through a telephone exchange, it is important that all connections be removed on the terminal board which might serve to impress telephone battery current on the particular circuit in use. If the instrument used be of high resistance and if the telephone or signal wires used as potential wires be of copper, it is rarely necessary to allow for the resistance of the latter in correcting the voltmeter readings.

Limiting Rail Drop should be Average rather than Maximum. In many municipal or other public requirements a limit has been placed on the potential drop in rails, and in many cases this limit has been expressed in terms of a maximum permissible drop. That this is unfair and that the limit should be expressed as an average drop is brought out by Messrs. McCollum and Logan in their paper on electrolytic corrosion (Trans. A.I.E.E., 1913) as follows:

"It is evident that if the total amount of damage which results is proportional to the average current, then the limitation of the average voltage is more logical than the limitation of the peak load voltage, since in the former case the cost of meeting the voltage limitation in any given case is proportionate to the danger involved irrespective of the station load factor; whereas if the voltage at peak load is the determining factor, the cost of complying with the requirement depends not only on the danger involved, but on the load factor of the system, and the poorer the load factor, the greater its cost will be. The rate of damage does not increase as fast as the voltage increases, because of the tendency toward lower corrosion efficiencies at higher current densities. This indicates that, with a given average all-day current, the actual amount of electrolysis that would occur would be less with a bad load factor than with a good load factor, and hence points to the undesirability of penalizing a high peak of short duration. It would appear very much more logical, therefore, in so far as the damage itself is concerned, to make the average all-day voltage the basis of the limitation rather than the voltage at time of peak load."

Methods of Reducing Earth Potentials and Currents thus Mitigating Electrolytic Corrosion

The methods which have been most often used with success in this country to reduce earth potentials and currents have been three; the insulated negative return feeder system, the insulating joint system, and the drainage system.

Insulated Negative Return Feeder System. In this system the tracks are drained of current at radially disposed points about the power station by insulated negative return feeder cables. The negative bus bar is not connected to the tracks nor to ground in the vicinity of the power station. Pressures as nearly equal as are required may be maintained at the track end of the return feeders by the use of rheostats on short feeders and boosters on long ones, or by greatly increasing the amount of copper in long feeders without the use of boosters or rheostats. The cost of the system increases very rapidly as the permissible maximum variation between the various portions of the track decreases. In a few American cities insulated negative return feeders have been installed in a portion of the city so as to secure an equipotential condition of the track in an area where the amount of underground cables or pipes subject to damage is the greatest. This method is feasible and most often used where the railway company's power station or substation is located very close to the center of distribution of a system composed of several or many lines radially disposed about the center of distribution. (See page 746.)

The insulating joint system requires that cable sheaths or piping systems should have insulating joints at frequent intervals. If the insulating joints be sufficiently numerous, this system may give good results, but there is some difficulty in applying them to an extensive system of underground cables, especially where the number of manholes is large and manholes crowded. Unless the number of insulating joints is sufficiently large to break up the potential around such joints to a very low value around each, there is also danger of current leaving the pipe or cable sheath on one side of the insulating joint and entering it on the other to such an extent that more or less serious corrosion is caused on the positive side of the joint. If every joint in the piping system were an insulating joint, this method would probably be an ideal one, as it would so increase the total resistance of the pipe line that the current flowing along it would be practically *nil*. This is illustrated in the case of some cast-iron gas mains where cement joints of high resistance are used and on which mains practically no current can be found.

Pipe Drainage System. In this system the pipe or cable sheaths in the positive district are connected to the negative side of the railway return circuits through low resistance cables. This system, as its name implies, drains the stray currents from the pipes or cable sheaths through metallic conductors so that practically no current leaves the pipe by way of the earth path. The drainage cables should preferably be connected directly to the negative bus bar at the power station or substation, and should be of very low resistance. In many cases a meter is installed in the connection to the negative bus, and in cases where the station shuts down for a portion of the day there should be a switch in the bus connections and the circuit should be opened when the station is not in operation. If the drainage system is properly installed, it will maintain the piping system and cable sheaths throughout their length at a potential lower than that of the rails. An objection which has been raised to the drainage system is that by reducing the total resistance to the flow of stray currents it thereby increases their volume and thus increases the damage which may be expected from "joint electrolysis," or the electrolytic action which may take place around a high resistance pipe joint due to the stray currents leaving the pipe on the positive side of the joint and returning on the negative side. Some evidence is on record of such damage, but the cases where such damage has occurred are extremely rare and where noted it has been caused either by isolated exceptionally high resistance joints or excessive current flow on the piping mains. Many cases are on record where a current density of 5 to 10 amperes per pound-foot or more has been carried on cast-iron water mains for years with no evidence of joint electrolysis. The drainage system has been used by the Bell telephone companies throughout the country for the protection of their cables for many years. In some cases city authorities have compelled the installation of the drainage system and in many cases they have allowed its use where the water system is owned by the city. The drainage system is very simple and much cheaper to install than the insulating joint method on a system of cables or pipes which are already in place in the ground, and is the system which has been in most common use in American cities either alone or in connection with the insulated negative return feeder system.

Electrolysis from Alternating Current. Mr. J. L. R. Hayden (Trans. A.I.E.E., 1907) draws the following conclusions relative to alternating-current electrolysis: It is not a phenomenon like direct-current electrolysis, on which definite quantitative general laws can be formulated, but is of the character of a secondary effect; that is, the action of the positive half wave is not quite reversed by the action of the negative half wave, leaving a small difference, rarely exceeding one-half of 1 per cent. of the electrolytic action of an equal direct current. Alternating-current electrolysis varies from practically nothing to somewhat less than 1 per cent. of direct-current electrolysis, varying with the chemical nature of the electrolyte and being practically independent of the current density. He states that protection from alternating-current electrolysis may be absolutely obtained by the super-imposition of a very small quantity of direct current upon the alternating, the amount of direct current being only 1.5 per cent. of the alternating current.

Transmission

Voltage Determination. The determination of the proper voltage for the transmission of energy requires a cost study made up of two parts, namely, the cost of the energy lost and the cost of the line, the transmitting and receiving apparatus. The amount and thus the cost of power lost in a given transmission line in delivering a given amount of power at the receiver end of that line decreases if the voltage at which that power is transmitted be increased. Such an increase in voltage necessitates an increase in the cost of insulation, apparatus and protective devices. Thus, under a given set of market conditions, the voltage at which a given amount of power will be delivered to a distant point at the least cost is limited to that value at which the sum of the cost of losses resulting and cost of line, transmitting and receiving apparatus necessary is a minimum. Kapp's modification of Kelvin's law of economy is: "The most economical area of conductor is that for which the annual cost of energy wasted is equal to the annual interest on that portion of the capital outlay which can be considered proportional to the weight of metal used." As the distance at which energy is transmitted increases, the cost of transmission line conductor and the losses in the line become of increasing importance relative to the cost of transmitting and receiving apparatus and the continuance of a given economy demands an increase in the voltage of operation. The amount of conductor required for a transmission line to transmit a given amount of power with a given loss on the line is reduced 75 per cent. each time the voltage at the receiver is doubled.

The more common transmission voltages are 2200, 4400, 6600, 11,000, 13,200, 22,000, 33,000, 44,000, 66,000, 88,000, 110,000, 140,000.

Spacing of Transmission Line Conductors. Transmission line conductors must be spaced far enough apart so that there will be no danger of arcing nor sparking between them and no danger of appreciable loss due to creepage or corona. The spacing must be given particular attention with regard to the possibility of the conductors swinging dangerously near together in the wind, especially where the direction of the wind is not at right angles to that of the transmission line. The separation of conductors required by the Joint Overhead Crossing Specification is shown on page 647.

Power Loss and Regulation of Transmission Line. The values of the power loss and regulation depend upon the amount of power delivered, the voltage at which it is delivered at the receiver end, the power factor of the load, the number of phases and the frequency of the system, the length of the line and the material, temperature, size, arrangement and distance apart of the conductors. For an approximate calculation of the power loss and regulation accurate enough for all ordinary electric railway work, it is sufficient to take into consideration the following items: Amount of power delivered, number of phases, voltage at receiver, power factor at receiver, resistance of the line and inductive reactance of the line. (Note that capacitance of the line is here omitted.)

Calculation of Power Loss and Regulation for Single-phase Two-wire Line. For three-phase see page 732.

$$\textit{Power Loss.}\ \text{(kilowatts line loss)} = \frac{I^2R}{1000}$$

in which I = current in line, amperes

$$= \frac{P \times 1000}{E \cos\theta}$$

P = power delivered at receiver, kilowatts

E = electromotive force at receiver, volts

$\cos\theta$ = power factor of load = power factor of receiver

R = resistance of line, ohms

= 2 × [resistance of one conductor, ohms (see pages 753 to 756)].

Example: To find the power loss in line delivering 2000 kw. at the receiver over a single-phase two-wire transmission line 60,000 ft. long composed of No. 1 A.W.G. (B. & S.) hard drawn solid copper wire; spacing of conductors, 36 in.; frequency, 60 cycles per second; electromotive force at receiver, 22,000 volts; power factor at receiver, 0.90 (current lagging).

Solution:

$$\text{(Current in line)} = \frac{2000 \times 1000}{22{,}000 \times 0.90}$$
$$= 101 \text{ amperes.}$$

From page 753 the resistance per 1000 ft. of No. 1 A.W.G. hard-drawn solid copper conductor is 0.1272 ohms; therefore:

$$\text{(resistance of line)} = R = 2 \times 60 \times 0.1272 = 15.26 \text{ ohms}$$

$$\text{(kilowatts loss in line)} = \frac{101^2 \times 15.26}{1000} = 155.7$$

Regulation.

$$\text{(per cent. regulation)} = 100 \times \frac{E_G - E}{E} \quad \text{(See Fig. 71).}$$

in which E_G = electromotive force at generator end of line, volts

$$= \sqrt{(E \cos\theta + IR)^2 + (E\sqrt{1 - (\cos\theta)^2} + IX)^2}$$

I = current in line, amperes

$$= \frac{P \times 1000}{E \cos\theta}$$

P = power delivered at receiver, kilowatts
E = electromotive force at receiver, volts
$\cos\theta$ = power factor of receiver (load)
R = resistance of line, ohms
= 2 × [resistance of one conductor, ohms (see pages 753 to 756)]
X = inductive reactance of line, ohms
= 2 × [inductive reactance of one wire, ohms (see pages 766 to 771)].

Following are three methods of calculating regulation: I. Solution by means of above analytical method. II. Solution by the use of the "Mershon Diagram" (Fig. 72) introduced by Mr. Ralph D. Mershon, American Electrician, 1897. III. Solution by a "drop-factor" method based on that of Messrs. Charles F. Scott and Clarence P. Fowler, Electric Journal, 1907.

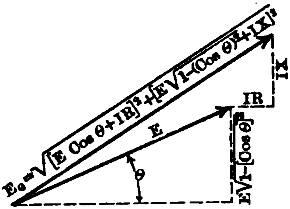

$E_G = \sqrt{[E \cos\theta + IR]^2 + [E\sqrt{1-(\cos\theta)^2} + IX]^2}$
E
θ
IR
IX
$E\sqrt{1-[\cos\theta]^2}$
$E \cos\theta$

FIG. 71.—E. M. F., diagram for single-phase line, capacitance neglected.

I. Direct Analytical Method of Calculating Regulation. Example: To find the per cent. regulation of line delivering 2000 kw. at the receiver over a single-phase, two-wire transmission line 60,000 ft. long composed of No. 1 A.W.G. (B. & S.) hard-drawnsolid copper wire; spacing of conductors, 36 in.; frequency, 60 cycles per second; electromotive force at receiver, 22,000 volts; power factors at receiver, 0.90 (current lagging).

Solution:

$$\text{(current in line)} = I = \frac{P \times 1000}{E \cos\theta}$$

$$= \frac{2000 \times 1000}{22{,}000 \times 0.90}$$

$$= 101 \text{ amperes.}$$

From page 753 the resistance per 1000 ft. of No. 1 A.W.G. hard-drawn solid copper conductor is 0.1272 ohms; therefore

$$\text{(resistance of line)} = R = 2 \times 60 \times 0.1272$$
$$= 15.26 \text{ ohms.}$$

From page 768 the inductive reactance per 1000 ft. of No. 1 A.W.G. solid conductor, spaced (interaxial distance) 36 in., is 0.13218 ohms; therefore

$$\text{(inductive reactance of line)} = X = 2 \times 60 \times 0.13218$$
$$= 15.86 \text{ ohms}$$

$$E_G = \sqrt{(E\ \cos\ \theta + IR)^2 + (E\sqrt{1 - (\cos\ \theta)^2} + IX)^2}.$$

(See Fig. 71.)

$$= \sqrt{(22{,}000 \times 0.90 + 101 \times 15.26)^2 + (22{,}000\sqrt{1 - 0.90^2} + 101 \times 15.86)^2}$$
$$= 24098$$

$$\text{(Per cent. regulation)} = 100 \times \frac{E_G - E}{E}$$
$$= 100 \times \frac{24{,}098 - 22{,}000}{22{,}000}$$
$$= 9.5 \text{ per cent. of receiver voltage.}$$

II. Method of Calculating Regulation by Use of Mershon Diagram. The method consists of first determining the resistance drop (called for convenience, "resistance volts") and the electromotive force required to balance the inductive reactance (called for convenience, "reactance volts"); these are then expressed in per cent. of receiver voltage and applied to the Mershon diagram (Fig. 72) from which the per cent. regulation is then read directly.

Example: To find the per cent. regulation of a line delivering 2000 kw. at the receiver over a single-phase, two-wire transmission line 60,000 ft. long composed of No. 1 A.W.G. (B. & S.) hard-drawn solid copper wire; spacing of conductors, 36 in.; frequency, 60 cycles per second; electromotive force at receiver, 22,000 volts; power factor at receiver, 0.90 (current lagging).

Solution:

$$\text{(current in line)} = I = \frac{P \times 1000}{E \cos \theta}$$
$$= \frac{2000 \times 1000}{22{,}000 \times 0.90}$$
$$= 101 \text{ amperes}$$

From page 753 the resistance per 1000 ft. of No. 1 A.W.G. hard-drawn solid copper conductor is 0.1272 ohms; therefore

$$\text{(resistance of line)} = R = 2 \times 60 \times 0.1272$$
$$= 15.26 \text{ ohms}$$
$$(\text{"resistance volts"}) = IR = 101 \times 15.26$$
$$= 1541 \text{ volts}$$
$$\text{(per cent. of receiver voltage)} = \frac{1541 \times 100}{22{,}000} = 7.0$$

From page 768 the inductive reactance per 1000 ft. of No. 1. A.W.G. solid conductor, spaced (interaxial distance) 36 in., is 0.13218 ohms; therefore

$$\text{(inductive reactance of line)} = X = 2 \times 60 \times 0.13218$$
$$= 15.86 \text{ ohms}$$

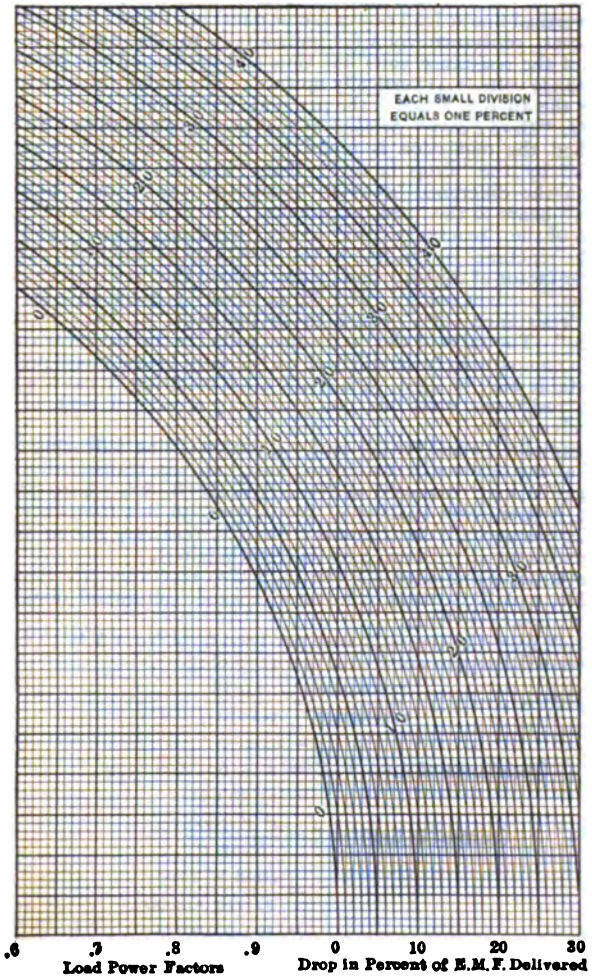


Fig. 72.—Mershon diagram.

$$(\text{"reactance volts"}) = IX = 101 \times 15.86$$
$$= 1602 \text{ volts}$$

$$(\text{per cent. of receiver voltage}) = \frac{1602 \times 100}{22{,}000} = 7.3$$

Now on the Mershon diagram (Fig. 3) from the point at which the vertical line at load power factor 0.90 cuts the arc 0, lay off the per cent. resistance volts (7) horizontally to the right. At the end of the resistance volts line thus laid off, lay off the per cent. reactance volts (7.3) vertically upward. The end of this line intersects the arc 9.5, which is the per cent. regulation.

III. "Drop Factor" Method of Calculating Regulation. In this method the regulation is found by multiplying the "resistance volts" by the "drop factor." This "drop factor" is the ratio which the difference between "generator volts" and "receiver volts" bears to the "resistance volts." It depends upon (1) the ratio of the "reactance volts" to the "resistance volts" (the ratio of the reactance of the line to the resistance of the line), (2) the power factor of the load, and (3) the ratio of the "resistance volts" to the "receiver volts." The "drop factor" is given on page 731 for "resistance volts" equal to 10 per cent. of the "receiver volts." The ratio of the "resistance volts" to the "receiver volts" has a comparatively small effect on the drop factor, consequently this table may be used, with small error resulting, in cases where the "resistance volts" do not exceed 15 or 20 per cent. of the "receiver volts."

Example: To find the per cent. regulation of line delivering 2000 kw. at the receiver over a single-phase, two-wire transmission line 60,000 ft. long composed of No. 1 A.W.G. (B. & S.) hard-drawn solid copper wire; spacing of conductors, 36 in.; frequency, 60 cycles per second; electromotive force at receiver, 22,000 volts; power factor at receiver, 0.90 (current lagging).

Solution: From page 768 the inductive reactance per 1000 ft. of No. 1 A.W.G. solid conductor, spaced (interaxial distance) 36 in., is 0.13218 ohm.

From page 753 the resistance per 1000 ft. of No. 1 A.W.G. hard-drawn solid copper conductor is 0.1272 ohm.

Therefore
$$\frac{\text{reactance}}{\text{resistance}} = \frac{0.13218}{0.1272}$$
$$= 1.04$$
$$(\text{resistance of line}) = R = 2 \times 60 \times 0.1272$$
$$= 15.26 \text{ ohms}$$
$$(\text{current in line}) = I = \frac{P \times 1000}{E \cos \theta}$$
$$= \frac{2000 \times 1000}{22{,}000 \times 0.90}$$
$$= 101 \text{ amperes}$$
$$(\text{"resistance volts"}) = IR = 101 \times 15.26$$
$$= 1541 \text{ volts}$$

From the table below the "drop factor" for a load power factor of 90 per cent. and the ratio of reactance to resistance of 1.04 is found by interpolation to be 1.39, therefore

$$\begin{aligned}(\text{regulation volts}) &= (\text{"resistance volts"}) \times (\text{"drop factor"})\\ &= 1541 \times 1.39\\ &= 2142 \text{ volts}\end{aligned}$$

$$(\text{per cent. regulation}) = \frac{2142 \times 100}{22{,}000} = 9.7$$

Drop Factors when Resistance Volts are 10 Per Cent. of the Receiver Volts

Ratio of reactance to resistance	Drop factors for power factors of (current lagging)								
	100%	95%	90%	85%	80%	70%	60%	40%	20%
0.10	1.00	1.00	1.00	0.94	0.88	0.80	0.70	0.60	0.30
0.20	1.00	1.01	1.01	0.98	0.92	0.86	0.82	0.67	0.40
0.30	1.00	1.05	1.05	1.02	0.99	0.93	0.89	0.74	0.50
0.40	1.00	1.08	1.10	1.08	1.04	1.00	0.93	0.82	0.60
0.50	1.00	1.11	1.14	1.13	1.10	1.07	1.01	0.92	0.70
0.60	1.01	1.15	1.18	1.19	1.15	1.14	1.09	1.01	0.80
0.70	1.02	1.18	1.23	1.24	1.21	1.20	1.17	1.11	0.91
0.80	1.02	1.21	1.28	1.29	1.28	1.27	1.24	1.20	1.01
0.90	1.03	1.25	1.33	1.34	1.34	1.35	1.32	1.29	1.11
1.00	1.04	1.28	1.37	1.39	1.40	1.41	1.39	1.38	1.20
1.10	1.05	1.32	1.41	1.44	1.45	1.48	1.47	1.46	1.30
1.20	1.06	1.35	1.46	1.50	1.51	1.55	1.54	1.55	1.40
1.30	1.07	1.39	1.51	1.55	1.57	1.62	1.63	1.64	1.49
1.40	1.08	1.43	1.55	1.61	1.64	1.70	1.71	1.72	1.59
1.50	1.10	1.47	1.60	1.67	1.70	1.77	1.80	1.81	1.70
1.60	1.10	1.51	1.65	1.74	1.77	1.85	1.87	1.90	1.80
1.70	1.13	1.55	1.70	1.79	1.84	1.92	1.95	1.99	1.90
1.80	1.15	1.59	1.76	1.85	1.91	1.99	2.04	2.08	1.99
1.90	1.17	1.63	1.82	1.91	1.98	2.06	2.11	2.16	2.08
2.00	1.18	1.68	1.87	1.96	2.04	2.14	2.19	2.25	2.18
2.10	1.20	1.72	1.92	2.03	2.10	2.21	2.28	2.35	2.28
2.20	1.22	1.77	1.98	2.09	2.17	2.29	2.37	2.45	2.38
2.30	1.23	1.82	2.03	2.15	2.23	2.37	2.45	2.53	2.48
2.40	1.25	1.87	2.09	2.22	2.30	2.44	2.53	2.62	2.58
2.50	1.27	1.91	2.14	2.28	2.37	2.52	2.60	2.71	2.67
2.60	1.30	1.95	2.20	2.34	2.44	2.60	2.67	2.80	2.76
2.70	1.32	1.99	2.26	2.41	2.51	2.68	2.74	2.98	2.86
2.80	1.35	2.05	2.32	2.47	2.57	2.76	2.82	3.07	2.95
2.90	1.37	2.10	2.39	2.54	2.64	2.83	2.91	3.15	3.05
3.00	1.40	2.15	2.45	2.60	2.72	2.90	3.00	3.23	3.15
3.10	1.42	2.20	2.51	2.66	2.80	2.97	3.10	3.31	3.25
3.20	1.45	2.26	2.57	2.73	2.87	3.05	3.20	3.39	3.35
3.30	1.48	2.31	2.63	2.80	2.93	3.12	3.30	3.47	3.45
3.40	1.51	2.36	2.69	2.87	3.00	3.20	3.39	3.56	3.54
3.50	1.53	2.42	2.74	2.94	3.08	3.27	3.48	3.65	3.63
3.60	1.57	2.47	2.80	3.00	3.15	3.35	3.56	3.75	3.72
3.70	1.60	2.52	2.86	3.07	3.23	3.43	3.65	3.85	

Calculation of Power Loss and Regulation for Three-phase Three-wire Line. The power loss and regulation for a given three-phase, three-wire line having its wires at the vertices of an equilateral triangle are equal to those, respectively, for a single-phase two-wire line of the same size of wire and the same spacing and supplying a load equal to one-half that supplied by the given three-phase line.

Example: To find the power loss and the per cent. regulation in a three-phase, three-wire line 60,000 ft. long composed of No. 1 A.W.G. (B. & S.) hard-drawn solid copper wire delivering 4000 kw. at the receiver; conductors at the vertices of an equilateral triangle and spaced 36 in.; frequency, 60 cycles per second; electromotive force at receiver, 22,000 volts; power factor at receiver, 0.90 (current lagging).

Solution: The power loss and per cent. regulation in this line will be equal to the power loss and per cent. regulation, respectively, in delivering 2000 kw. at the receiver over a single-phase, two-wire transmission line 60,000 ft. long composed of No. 1 A.W.G. (B. & S.) hard-drawn solid copper wire; spacing of conductors, 36 in.; frequency, 60 cycles per second; electromotive force at receiver, 22,000 volts; power factor at receiver, 0.90 (current lagging). Solving this single-phase line the loss is 155.7 kw. and the regulation is 9.5 per cent. That is, the loss and regulation in the above three-phase line are 155.7 kw. and 9.5 per cent., respectively.

Positive Feeder System

The design of distribution feeders and the location of substations must be considered together in determining the best distribution system for any particular track, equipment and condition of traffic. There is no general method of locating substations and designing distribution feeders. Each system must be dealt with according to its particular requirements and limitations. A change in track, equipment, condition of traffic, any or all of them, may not be sufficient to justify a relocation of substations unless the portable substation be used, but may be such as to necessitate a redesign of feeders. It should be noted that the use of the portable substation demands a provision for ample transmission supply to the point at which the substation is to be connected to the transmission line. The distribution system must be so designed that the maximum drop in potential to cars at all points on the line shall not exceed that which will leave a sufficient voltage for the satisfactory operation of traction motors and auxiliary apparatus at such points. In addition to this, the conductors must be of such a size and length and must be so related that each will carry its share of current without undue heating. The original distribution should be designed to fill these requirements at the minimum yearly cost possible for the particular installation being investigated and this should be attempted in all future developments of that installation. In many cases the limitations met in such future development will prevent the attainment of such a low yearly cost as was possible in the case of the original distribution at the beginning of its operation. In either case the quality of service required should first be considered, and the financial considerations made secondary.

The design of feeders and the location of substation must be according to load and its distance rather than distance alone, thus for the same drop in potential the distance from substation to a given load would have to be less than that with a smaller load. That the energy be delivered with no greater than the maximum allowable drop in potential must be the first provision. That is, the energy must be delivered at a potential at least sufficient to accelerate the trains, enable them to climb grades, operate auxiliary apparatus such as air compressors and contactors and furnish satisfactory lights, heat and ventilation.

A graphical train schedule (see page 137) is useful in the study of an interurban distribution system. This shows the location and speed of trains at any and all parts of the day, it also shows the location of stations, turnouts, grades and curves. Trolley, feeder, transmission line layouts and substation locations may be added to the graphical schedule for convenience in the future. From the schedule the condition of regular traffic which will cause the greatest drop in potential may be approximated. The condition of greatest demand upon a given substation may also be approximated from the schedule.

Where local regulations require that an insulated return such as may be provided by a double trolley or conduit system shall be used, the supply and return portions of the distribution are generally designed alike. Where the track rails are used for a return, the supply feeders must be so designed that the potential drop in the supply feeders shall not be greater than the difference between the total allowable drop from substation to car and the drop in the track return.

Distribution systems divide into two general classes, namely, interurban and city. These classes are characterized by the frequency of service. The interurban distribution must be designed to limit the maximum drop to starting trains or trains operating under very severe grade conditions. In city distribution where the current required to start an individual train alters the average current but slightly, the distribution is designed for the average current demanded by the trains operating on the section under consideration. Such design will be further influenced by concentrated rush loads of considerable duration.

The position and equipment of substations will often be determined by prominent load centers together with real estate and other business conditions peculiar to the problem in hand. Where, however, there is not such a guide it may be necessary to decide upon the number of substations necessary to feed the section under consideration. The number of stations with which there will result the least total annual cost will in this case be the best. This may be decided upon by calculating the total annual cost for each of several numbers of stations. For convenience in arriving at this total cost the value of each of the eight following parts may be determined and these added together:

1. Annual charges on substation buildings and land.
2. Annual charges on substation equipment.
3. Annual charges on distribution conductor (feeders, trolley wire, third rail, their supports, etc.).
4. Annual charges on transmission system.
5. Annual cost of substation attendance.
6. Annual cost of substation losses.
7. Annual cost of losses in distribution conductors.
8. Annual cost of transmission losses.

Mr. H. F. Parshall, British Institution of Civil Engineers, 1914, draws the following conclusions from an elaborate study based largely upon operating costs of the Central London Railway. They illustrate briefly the influence of the important factors which determine the cost of a distribution system. With the given energy consumption per unit of length of line that follows from a given train movement, the capacity of the substations increases directly with the distance between them. The energy loss in distribution conductors of a given section varies with the cube of the distance between substations. The cost of attendance is within wide limits independent of the size of the substation. The cost of the plant per kilowatt falls off with the size of the units, but the maintenance and renewals per kilowatt are more or less constant. With rotary converter substations and a working voltage of 600, and for certain assumed energy consumption, the most economical substation spacings are 8½ miles, 5½ miles and 3¼ miles for train service of six, twelve and twenty-four trains per hour, respectively. For a working voltage of 1200, the substation spacings are 11 miles, 7¼ miles and 5 miles, respectively, while when 2400 volts are adopted the most economical substation spacings are 16 miles, 12 miles and 8½ miles for the three train services, respectively. With the present arrangement of rotary converter substations, there is little advantage in a higher voltage than 2400 for the track conductor. The economy of higher voltages is shown to be approximately the same whatever the train service. As between 600 volts and 1200 volts there is a saving of 14 per cent. in the total annual costs of the distribution system; as between 1200 volts and 2400 volts there is a further saving of 7 per cent. or 21 per cent. as between 600 volts and 2400 volts. If the working voltage is further increased to 3600, there is a decrease in total annual expenditure on substation and overhead conductor equipment of only 3 per cent., which will be less than the additional cost of the rolling stock. For single-phase distribution at 5000 volts the most economical substation spacings are 31 miles, 24 miles and 16 miles for train services of two, three and six trains per hour, respectively. At 10,000 volts single-phase, the most economical substation spacings are 45 miles, 34 miles and 26 miles for the same three train services, respectively. With three-phase distribution at 5000 volts, the most economical distances between substations are 38 miles, 31 miles and 18 miles for the same respective train services. In most of these last cases, however, the economical distance between substations thus determined is greater than would be permissible in practice from considerations of both traffic operation and voltage drop. Further, in the case of the single-phase operation, the lower pressure of 5000 volts is found to be the most economical for certain services and the higher pressures of 10,000 volts, 12,000 volts and 15,000 volts in vogue in Europe are explained by consideration of voltage drop.

Mr. W. S. Murray, in commenting on the above quoted paper, points out that Mr. Parshall has assumed a power factor for the single-phase distribution of from 40 to 45 per cent. Mr. Murray states that this is but little more than one-half of that which would obtain in actual practice and points out that the single-phase substation spacing should be considerably greater than that given in Mr. Parshall's paper if the proper power factor and the same size train units are assumed.

City Distribution System. The design of a city distribution system may be well outlined by a typical case, namely, the rehabilitation of the Chicago surface lines. The following is from the Second Annual Report of the Board of Supervising Engineers, Chicago Traction:

"It was the sense of the Board that the direct-current feeder copper for the Chicago Railways Company and the Chicago City Railway Company should be figured on a basis of 75 amperes per car between the direct-current bus bars of substations or power houses, and the point of delivery at the car; it being understood that it is the intention of both roads to carry the voltage somewhat lower than 600 volts at the station bus bars until such time as, through the elimination of low voltage motors and otherwise, they are able to raise the voltage to 600 volts. After discussion the following resolution was unanimously adopted:

"*Resolved*, That the system of secondary or direct-current electrical conductors or feeders for the Chicago Railways Company and the Chicago City Railway Company shall be calculated and plans made therefor by the Chief Engineer of the Work on the following basis:

"1. That the direct-current bus bar at power houses or substations will be operated at approximately 600 volts.

"2. That an allowance of 40 kw. in power house and substation capacity for each standard double truck car of the type approved by the Board of Supervising Engineers, weighing approximately 26 tons light, or its equivalent, will be provided at each direct-current bus bar.

"3. That in calculating the copper for current-carrying capacity an allowance of 75 amperes for each standard double truck car, as described above, or its equivalent, shall be allowed.

"4. That an average* drop of 50 volts will be allowed between the direct-current bus bars and the center of gravity of the trolley section, due provision being made for suitable tie lines to take care of emergency cases.

"5. That the carrying capacity of insulated underground cables shall be calculated upon the following basis:

---

* This refers to the average maximum for the 2-hour morning and evening rush periods. In majority of cases the drop is less than 50 volts.

	Lead covered	Paper covered	Triple braided weatherproof
1,000,000 circ. mils cable amp...	800	1000	1250
500,000 circ. mils cable amp...	500	600	625
350,000 circ. mils cable amp...	375	425	325
4/0 cable amperes............	....	....	325

"In arriving at the kilowatts and amperes per car stated in the foregoing resolution a series of tests was made jointly by representatives of the Chicago City Railway Company, the Chicago Railways Company and the Division of Electrical Transmission and Distribution.

"Tests were first made upon a single car by equipping it with instruments and stationing observers upon it to record the results in actual operation on different kinds of service.

"Tests were also made upon groups of eighteen to seventy-six cars operating on an isolated trolley section of a mile or more in length by stationing observers to note the cars entering and leaving the section and also to take readings on station switchboards of the current and voltage on the feeders to the sections at 15-second intervals.

Tests on Single Car. Car tested: Chicago City Railway Company's Pay-as-you-enter car No. 5446. Scale weight: 55,800 lb. or 27.9 tons. Motor equipment: Four 40-h.p., No. G. E.—80 motors. Motor control: No. K–28–E. Gear ratio: 69 : 17 or 4.06 : 1 with 33-in. wheels. Air brakes: With 16-ft. compressor set for range of 60 to 85 lb. Heaters: Electric, consisting of 14 truss plank heaters, 4 panel heaters, 2 platform heaters. Lighting: Eighteen 16-c.p. side lights, three 32-c.p. center lights, one 16-c.p. platform light, one 32-c.p. headlight.

SUMMARY OF FIFTEEN TESTS ON SINGLE CAR, MAY 28 TO JUNE 1, 1908

	Minimum	Maximum	Average
Passengers, crew and observers........	17.0	63.0	30.4
Weight in tons, car and live load......	29.09	32.31	30.03
Schedule speed in miles per hour.......	7.69	11.04	8.91
Volts at car......................	450.0	545.0	494.0
Heater energy, kw.:			
First point (5 tests)...............	2.865	2.89	2.87
Second point (5 tests)..............	5.006	5.015	5.01
Third point (6 tests)...............	7.62	7.79	7.74
Lighting energy, kw. (5 tests).......	1.603	1.612	1.61
Total energy, kw. at car:			
Motors and compressor............	28.21	46.50	37.19
Motors, compressor and lights.......	29.82	48.11	38.80
Same with 1 point heat............	32.69	50.98	41.61
Same with 2 points heat...........	34.83	53.12	43.81
Same with 3 points heat...........	37.56	55.85	46.54
Amperes at 550 volts at car motors, compressor, lights and 2 points heat.	63.33	96.58	79.66

SUMMARY OF SECTION TESTS, JUNE 11, 1908
TWO HOURS MAXIMUM SERVICE

	Minimum	Maximum	Average
Number of cars on section	23.3	75.7	62.7
Amperes to section at station	1686.0	4076.0	3430.0
Amperes per car at station	49.4	80.2	55.45
Adding 10 per cent. for winter load	54.3	88.2	61.00
Adding 12 amperes for lights and 2 points heat	66.3	100.2	73.00
Kw. at station	27.5	44.0	32.5
Adding 10 per cent. for winter load	30.3	48.4	35.8
Adding 6.62 for lights and 2 points heat.	36.9	55.0	42.4

"It was assumed that the average maximum condition for which feeders should be provided would be when a car was operating with motors, compressor, lights and two points on heaters. On this basis the individual and section tests compare as follows per car:

	Minimum	Maximum	Average
Individual car tests:			
Kw. at car	34.83	53.12	43.81
Amperes at car	63.33	96.58	79.66
Section tests:			
Kw. at station	36.9	55.0	42.4
Amperes at station	66.3	100.2	73.0

"The calculations for feeder requirements for the Chicago City Railway system are briefly outlined. This system is used because the calculations have been practically completed during the year.

"1. From the proposed operating schedules the total number of cars which were required during the "rush" hours was distributed and plotted upon a skeleton map of the system, which is called a 'Spot Map.' The afternoon maximum period is usually the heaviest service period, so that the car distribution for 2 hours of what is styled the 'P. M. Rush' was used on this map.

"2. The trolley sections were then drawn and the number of cars on each multiplied by 75, which gives the total average maximum load for each individual trolley section in amperes. This amount was placed in a small circle at the center of gravity of the trolley section.

"3. A study was then made of the proper location of stations. The best probable locations were selected and a calculation of load centers was made by finding the combined center of gravity of the loads about a given station. If a given system was to be fed by a single power house, the system load center was also determined, which showed the most economical location so far as distribution of copper was concerned for the generating station. If the locations chosen were not the most economical for distribution of copper, studies were made of comparative costs for other locations where the company might have property or where real estate for substation purposes might be obtained to advantage.

"4. After the station locations were definitely settled and the sections to be fed from each station were decided upon, a 'spider diagram' was added to the drawing, which then became a drawing of record, and showed at a glance what sections were fed from any given station and what average maximum load was to be expected upon that section (see Fig. 73).

"5. The most desirable routes for the cables were then determined, drawn upon a diagram and the distances measured from station bus bar to the load center of each trolley section.

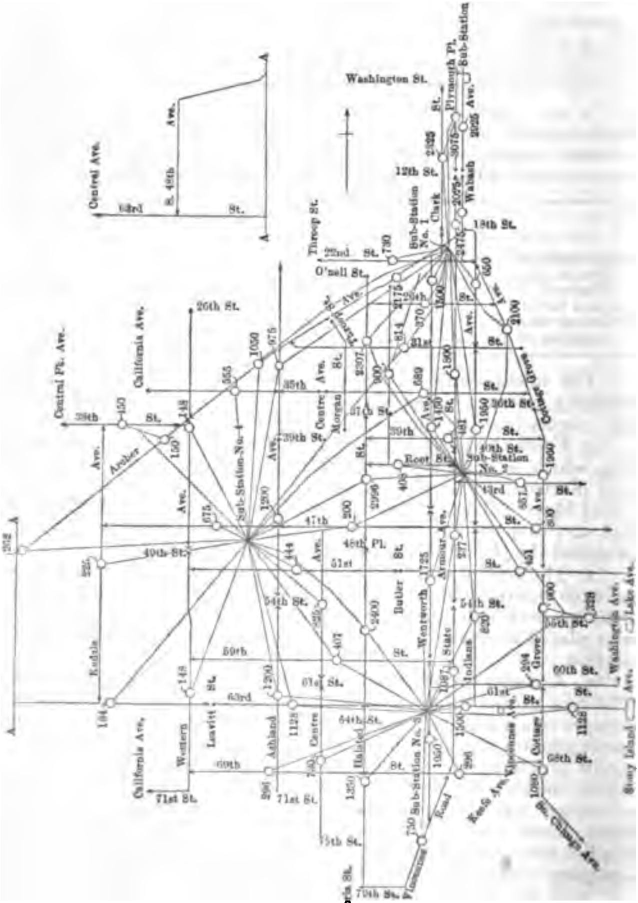


FIG. 73.—Trolley section map and spider diagram, Chicago.

"6. The size of each feeder was then calculated in accordance with the requirements of Resolution No. 562 (page 735). The known elements are:

A. Load in amperes.
B. Distance in feet.
C. Drop in potential, 50 volts more or less.
D. Unit sizes of cables and carrying capacity of each.

From these the size of cable was calculated or read directly from the curves without calculation (see Fig. 75).

"7. A certain number of the more important trolley sections are fed from two separate stations in such a way that in case of the shut-down of one station or of accident to one feeder, the cars on the section could still be operated from the other station, or by means of the other feeder. These are designated as 'tie-sections' and in addition to the above advantages, are so proportioned and calculated that on the whole system in case of the shut-down of one or two stations, a certain proportion of the cars can be carried on the remaining stations by interconnecting through these tie lines.

"8. Where the ordinances required feeders to be placed underground, it was necessary to lay out underground conduit lines. A diagram is used for this; the number of cables over a given section being represented arbitrarily by the numerator of a fraction, and the number of ducts by the denominator. Extra ducts are installed in all conduit lines where practicable, to provide for future growth without tearing up pavements. The percentage of extra ducts will vary for different locations, depending upon the estimates of future requirements."

Feeder Calculations

Significance of symbols in following Cases I to X, inclusive:

$(C.M.)$, $(C.M.)_1$, $(C.M.)_2$ = cross-sectional area of conductor at 20 deg. C., 68 deg. F., expressed in circular mils. [NOTE: This may be the cross-sectional area of one solid conductor or the combined cross-sectional areas of two or more conductors of *equal length* operating in parallel to give the equivalent cross-sectional area of one large conductor. This includes the case of combined working conductor (trolley wire or third rail) and feeder tied together at short intervals.]

e, e_a, e_b = potential drop in feeder as indicated below, volts.

I = total current uniformly distributed along section, amperes.

I_a and I_b = current taken from conductor at points a and b, respectively, amperes.

I_A, I_B, I_1, I_2, I_3 = current as indicated below, amperes.

K = direct current resistivity of conductor, ohms per circular mil foot.

$$l_2 = \frac{e_a - I_a r_1 l}{I_a r_2 - I_a r_1}$$

also $l_2 = l - l_1$

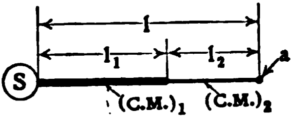


FIG. 76.

Case III. (Fig. 77.) Total load of I amperes uniformly distributed, conductor of uniform cross-section.

$$(C.M.) = \frac{IKl}{2e}$$

(Volts drop to end of section) $= e = \dfrac{Irl}{2}$

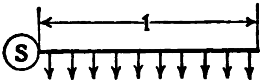


FIG. 77.

Case IV. (Fig. 78.) Load concentrated at a point, conductors as in Fig. 78.

(Volts drop to point a) =

$$e_a = I_a\left[r_1 l_1 + \frac{1}{\left(\frac{1}{r_2 l_2}\right) + \left(\frac{1}{r_3 l_3 + r_4 l_4}\right)}\right]$$

(Amperes in conductor A) =

$$I_A = I_a\left[\frac{(r_3 l_3 + r_4 l_4)}{(r_2 l_2 + r_3 l_3 + r_4 l_4)}\right]$$

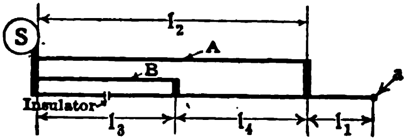


FIG. 78.

(Amperes in conductor B) =

$$I_B = I_a\left[\frac{r_2 l_2}{(r_2 l_2 + r_3 l_3 + r_4 l_4)}\right]$$

also $I_B = I_a - I_A.$

Case V. (Fig. 79.) Load concentrated at a point, conductors as in Fig. 79.
(Volts drop to point *a*) =

$$e_a = I_a\left[\frac{1}{\left(\frac{1}{r_3l_3 + r_4l_4}\right) + \left(\frac{1}{r_2l_2 + r_5l_5}\right)}\right]$$

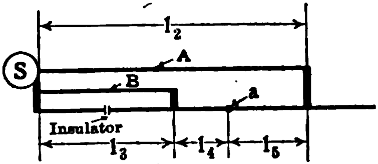


FIG. 79.

(Amperes in conductor *A*) =

$$I_A = I_a\left[\frac{(r_3l_3 + r_4l_4)}{(r_2l_2 + r_3l_3 + r_4l_4 + r_5l_5)}\right]$$

(Amperes in conductor *B*) =

$$I_B = I_a\left[\frac{(r_2l_2 + r_5l_5)}{(r_2l_2 + r_3l_3 + r_4l_4 + r_5l_5)}\right]$$

also $I_B = I_a - I_A$.

Case VI. (Fig. 80.) Load concentrated at a point, conductor of uniform cross-section (*C.M.*, of *r* ohms resistance per foot), source of supply at each end of conductor, sources of supply at the same potential, track return assumed to be of uniform resistance per foot.

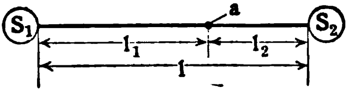


FIG. 80.

$$(C.M.) = \frac{I_aKl_1l_2}{e_al}$$

(Volts drop to point *a*) $= e_a = \frac{I_arl_1l_2}{l}$

(Amperes in section l_1, supplied by S_1) $= I_1 = \frac{I_al_2}{l}$

(Amperes in section l_2 supplied by S_2) $= I_2 = \frac{I_al_1}{l}$

also $I_2 = I_a - I_1$

Case VII. (Fig. 80.) Load concentrated at a point, conductor not of uniform cross-section but of cross-section $(C.M.)_1$ having a resistance of r_1 ohms per foot from source S_1 to point *a* and of cross-section $(C.M.)_2$ having a resistance of r_2 ohms per foot from source S_2 to point a, source of supply at each end of conductor, sources of supply at the same potential, track return assumed to be of uniform resistance (R ohms per foot).

(Volts drop to point a) =

$$e_a = I_a\left[\frac{r_1 l_1 l_2(r_2 + R)}{l_1(r_1 + R) + l_2(r_2 + R)}\right]$$

(Amperes in section l_1 supplied by S_1) =

$$I_1 = I_a\left[\frac{l_2(r_2 + R)}{l_1(r_1 + R) + l_2(r_2 + R)}\right]$$

(Amperes in section l_2 supplied by S_2) =

$$I_2 = I_a\left[\frac{l_1(r_1 + R)}{l_1(r_1 + R) + l_2(r_2 + R)}\right]$$

also $$I_2 = I_a - I_1$$

Case VIII. (Fig. 81.) Load concentrated at two points, conductor of uniform cross-section (having a resistance of r ohms per foot), source of supply at each end of conductor, sources of supply at the same potential, track return assumed to be of uniform resistance per foot.

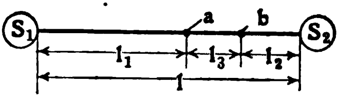


FIG. 81.

(Volts drop to point a) = $e_a = I_1 r l_1$
(Volts drop to point b) = $e_b = I_2 r l_2$
(Amperes in section l_1 supplied by S_1) =

$$I_1 = \frac{I_a(l_2 + l_3) + I_b l_2}{l}$$

(Amperes in section l_2 supplied by S_2) =

$$I_2 = \frac{I_a l_1 + I_b(l_1 + l_3)}{l}$$

also $$I_2 = I_a + I_b - I_1$$

(Amperes in section l_3) = $I_3 = I_1 - I_a$

(NOTE: In case the value of I_3 thus obtained is minus, this minus sign indicates that I_3 is supplied by S_2).

Case IX. (Fig. 81.) Load concentrated at two points, conductor *not* of uniform cross-section (sections l_1, l_2 and l_3 having resistances of r_1, r_2 and r_3 ohms per foot respectively), source of supply at each end of conductor, sources of supply at the same potential, track return assumed to be of uniform resistance (R ohms per foot).

(Volts drop to point a) = $e_a = I_1 r_1 l_1$
(Volts drop to point b) = $e_b = I_2 r_2 l_2$
(Amperes in section l_1 supplied by S_1) =

$$I_1 = \frac{I_a l_3(r_3 + R) + l_2(I_a + I_b)(r_2 + R)}{l_1(r_1 + R) + l_2(r_2 + R) + l_3(r_3 + R)}$$

(Amperes in section l_2 supplied by S_2) =

$$I_2 = \frac{l_1(I_a + I_b)(r_1 + R) + I_b l_3(r_3 + R)}{l_1(r_1 + R) + l_2(r_2 + R) + l_3(r_3 + R)}$$

also $\quad I_2 = I_a + I_b - I_1$

(Amperes in section l_3) = $I_3 = I_1 - I_a$

(NOTE: In case the value of I_3 thus obtained is minus, this minus sign indicates that I_3 is supplied by S_2).

Case X. (Fig. 82.) Total load of I amperes uniformly distributed, conductor of uniform cross-section, source of supply at each end of conductor, sources of supply at the same potential.

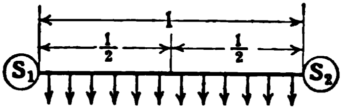


FIG. 82.

(Volts drop to center of section) = $e = \frac{Irl}{8}$

(Cross-section of conductor for drop e to center of section) =

$$(C.M.) = \frac{IKl}{8e}$$

(Amperes supplied by S_1) = $I_1 = \frac{I}{2}$

(Amperes supplied by S_2) = $I_2 = \frac{I}{2}$

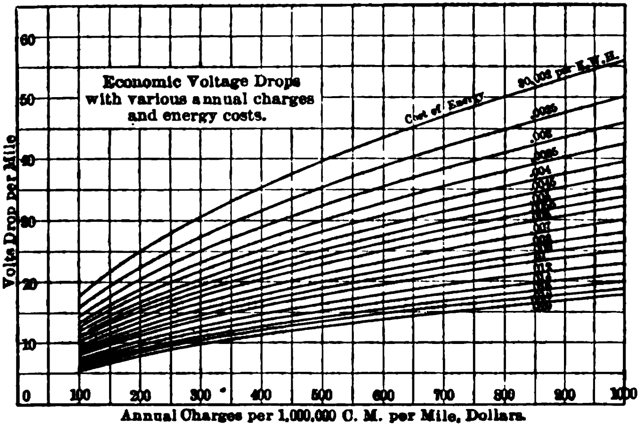


FIG. 83.

Economical Voltage Drop in Conductors. Fig. 83 affords a means of rapidly approximating the most economical voltage drop per mile of conductor for a given cost of energy lost and given annu charges against the installation. These curves were derived according to Kapp's modification of Kelvin's law, which is: "The most economical area of conductor is that for which the annual cost of energy wasted is equal to the annual interest on that portion of the capital outlay which can be considered proportional to the weight of metal used." Example: When the annual charges are $450 per mile per 1,000,000 circular mils of conductor and the cost of energy lost is $0.007 per kilowatt hour, what is the most economical voltage drop per mile of conductor? Beginning at $450 point on the horizontal scale, follow the vertical to its intersection with the $0.007 curve. From this point follow the horizontal to the scale on the left. The intersection with this scale shows that the most economical voltage drop per mile in this particular case is 20.

Negative Return Systems

Uniformly Distributed Load, Track Extending in one Direction (no Network). The curves and formulas, Figs. 84 to 90, inclusive, from a paper by Mr. G. I. Rhodes, A.I.E.E., 1907, are theoretical, giving convenient comparisons of voltage drop, earth currents and amounts of auxiliary negative conductor necessary, for various return systems in which the load is uniformly distributed over the whole line which extends in one direction only from the power station. It is also assumed that the only resistance in the path of the earth current is the contact resistance between rail and ground. This is a safe assumption, as it gives the highest possible values of earth current. These curves show that the way to obtain a minimum of stray current from the grounded rails of a single-trolley electric road is to insulate the negative bus bar, and to employ two or more insulated return feeders either so proportioned in resistance or provided with negative boosters as to produce equal potentials at their connecting points to the rails. The following seven general cases are considered: I. No copper in return circuit. II. Copper of uniform section bonded to the rails at short intervals. III. Copper distributed to give uniform drop, bonded to the rails at short intervals. IV. A single insulated negative feeder connected to rails at middle of the line and at the power station. V. A single insulated feeder connecting the rails to the negative bus bar only at the middle of the line. VI. Several insulated feeders. VII. Several insulated feeders with equal potentials at all feed points. In Figs. 84 to 86, inclusive, the ordinates of the curves are proportional to the voltage drop (100 per cent. voltage drop $= \frac{\rho I L}{2 S_i}$ = drop to end of line, Case I) and the area beneath the curve is a measure of the earth or leakage current.

The significance of symbols is as follows:

i = current at any point on line
I = total current
v = potential at any point referred to bus bar as zero
l = distance from power station
L = total length of line

L_o = distance to point at which, with bus bar insulated, rail and earth are at same potential
r = resistance per foot of return
ρ = resistance per cir. mil-foot of copper = 10.37 ohms
w = weight per cir. mil-foot of copper = 0.00000302 lb.
S_i = equivalent conductivity of track rails in cir. mils of copper
S_e = cir. mils of return copper at power station
W = weight of return copper
A = area representing leakage current with negative bus bar grounded
a = area representing leakage current with negative bus bar insulated.

I. No return copper:

$$v = \frac{\rho IL}{2S_i},\ A = \frac{\rho IL^2}{3S_i},\ L_o = L\left(1 - \frac{1}{\sqrt{3}}\right),\ a = \frac{1}{3\sqrt{3}}\left[\frac{\rho IL^2}{3S_i}\right]$$

II. Return copper of uniform section:

$$v = \frac{\rho I}{S_i + S_e}\left(l - \frac{l^2}{2L}\right),\ A = \frac{S_i}{S_i + S_c}\left[\frac{\rho IL^2}{3S_i}\right],\ L_o = L\left(1 - \frac{1}{\sqrt{3}}\right)$$

$$a = \frac{S_i}{3\sqrt{3}(S_i + S_c)}\left[\frac{\rho IL^2}{3S_i}\right],\quad W = wS_eL$$

III. Copper distributed for uniform drop:

$v = \frac{\rho Il}{S_i + S_e}$ a straight line up to the point at which $l = L_1 = L\frac{S_c}{S_i + S_e}$ but for values of l greater than L_1,

$$v = \frac{\rho I}{S_i}\left[\frac{(L - L_1)(l - L_1)}{L} - \frac{(l - L_1)^2}{2L}\right] + \frac{\rho IL_1}{S_i + S_e}$$

$$A = \frac{S_i(3S_e^2 + 6S_iS_c + 2S_i^2)}{2(S_i + S_c)^3}\left[\frac{\rho IL^2}{3S_i}\right] \qquad L_o = \frac{L}{2}\left[1 - \frac{S_i^2}{3(S_i + S_c)^2}\right]$$

$$a = \frac{S_i(3S_c^2 + 6S_iS_e + 2S_i^2)^2}{24(S_i + S_c)^5}\left[\frac{\rho IL^2}{3S_i}\right] \qquad W = \frac{wS_e^2L}{2(S_i + S_e)}$$

IV. Single insulated return feeder from middle of line. Connection to rails at power house:

From $l = 0$ to $l = \frac{L}{2}$ $\qquad v = \frac{\rho I}{S_i}\left[l\left(1 - \frac{3S_c}{4(S_i + S_c)}\right) - \frac{l^2}{2L}\right]$

From $l = \frac{L}{2}$ to $i = L$

$$v = \frac{\rho I}{S_i}\left[\frac{\left(l - \frac{L}{2}\right)}{2} - \frac{\left(l - \frac{L}{2}\right)^2}{2L} + \frac{L}{2}\left(\frac{3S_i}{4(S_i + S_c)}\right)\right]$$

$$A = \left[1 - \frac{27S_e}{32(S_i + S_c)}\right]\frac{\rho IL^2}{3S_i}$$

$$L_o = L\left[1 - \frac{1}{\sqrt{3}}\sqrt{1 - \frac{9S_e}{16(S_i + S_c)}}\right]$$

$$a = \frac{1}{3\sqrt{3}}\left(1 - \frac{9S_e}{16(S_i + S_c)}\right)^{3/2}\left[\frac{\rho IL^2}{3S_i}\right] \qquad W = \frac{wS_eL}{2}$$

V. A single insulated return feeder from middle of line. No other connection to rail:

From $l = 0$ to $l = \frac{L}{2}$
$$v = \rho I L\left[\frac{1}{2S_c} + \frac{1}{8S_i}\right] - \frac{\rho I l^2}{2LS_i}$$

and from $l = \frac{L}{2}$ to $l = L$
$$v = \frac{\rho I}{S_i}\left[\frac{\left(l-\frac{L}{2}\right)}{2} - \frac{\left(l-\frac{L}{2}\right)^2}{2L} + \frac{LS_i}{2S_c}\right]$$

$$A = \frac{6S_i + S_c}{4S_c}\left[\frac{\rho I L^2}{3S_i}\right] \qquad L_o = \frac{L}{2\sqrt{3}} \text{ and } L_o = \frac{L}{2}\left[1 - \frac{1}{\sqrt{3}}\right]$$

$$a = \frac{1}{12\sqrt{3}}\left[\frac{\rho I L^2}{2S_i}\right]$$

(The weight of copper is the same as in Case IV)

VI. With several insulated feeders the potential curve will take a form similar to that of Case V in which the curve between any two feeders is a portion of the parabola of Case I. If the feeders are of uniform size, the general form of the potential curve will approach the straight line of Case III as the number of feeders is increased indefinitely. With a single feeder the area measuring leakage current is larger than for the case with the copper distributed for uniform drop, and with increasing number of feeders this area will approach it as a limit. With feeders graded in size to give uniform potential at the feed points, the curves will be of the forms in Case VII.

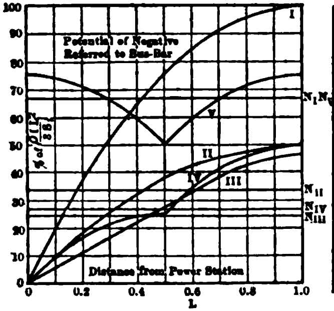


FIG. 84.—Potential curves, Cases I–V.

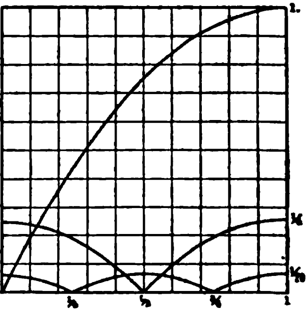


FIG. 85.—Potential of negative referred to bus bar, Case VII.

VII. Several insulated feeders with equal potentials at feed points. In this case the uniformly equal potentials at the ends of feeders may be secured by properly adjusting the sizes or by means of negative boosters. By adjustment of sizes, the potential of the track must necessarily be greater than that of the bus bar, and if there is a solid ground at the power station there will be a leakage current due to this difference; but with the use of boosters the potentials at the ends of the feeders can be maintained uniform with the negative bus bar. For the best results with a given number of feeders it is evident that they must be connected to the rails at such points as will give equal maxima on the potential curves. This may be accomplished in two ways:

1. No connection to rails at power station, and distance between feed points twice the distance from the power house to the first point, and from the last point to the end of the line (see Fig. 85).

2. Connection to rails at power house with the distance between feed points, and from the power station to the first feed point equal to twice the distance from the last point to the end of the line (see Fig. 86).

1. With a single feeder and no connection at power house, the feed point for equal maxima will be at the center of the line (see Fig. 85), the potential curve being made up of the upper portions of the parabola of Case I, also shown in Fig. 85.

With the bus bar grounded the area beneath this curve is

$$A = \frac{1}{4}\left[\frac{\rho IL^2}{3S_i}\right]$$

With two feeders the feed points will be one-fourth and three-fourths of the distance from the power house and the area will be

$$A = \frac{1}{16}\left[\frac{\rho IL^2}{3S_i}\right]$$

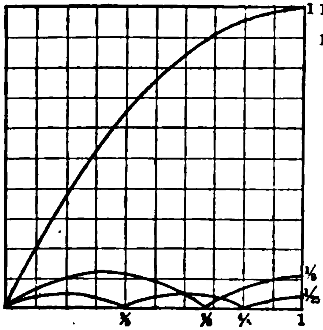


FIG. 86.—Potential of negative referred to bus bar, Case VII.

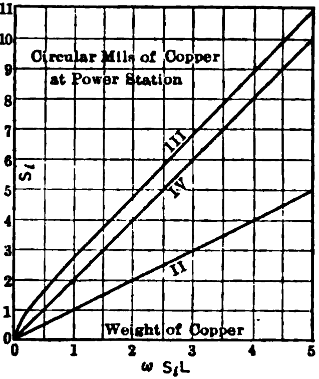


FIG. 87.—Weight of copper in negative feeders.

With n feeders the feed points will be at $\frac{1}{2n}$, $\frac{3}{2n}$ . . . $\frac{2n-1}{2n}$ of the distance from the power house to the end of the line, making

$$A = \frac{1}{4n^2}\left[\frac{\rho IL^2}{3S_i}\right]$$

2. With one feeder the point of connection to the rails will be at $= \frac{2}{3}L$, making

$$A = \frac{1}{9}\left[\frac{\rho IL^2}{3S_i}\right]$$

With two feeders the point of connection will be at $l = \frac{2}{5}L$, and $\frac{4}{5}L$, making

$$A = \frac{1}{25}\left[\frac{\rho I L^2}{3S_i}\right]$$

With n feeders the feed points will be at $l = \frac{2}{2n+1}L, \frac{4}{2n+1}L$ $\ldots \frac{2n}{2n+1}L$, making

$$A = \frac{1}{(4n+\frac{1}{2})^2}\left[\frac{\rho I L^2}{3S_i}\right]$$

Making a connection to the bus bar, in addition to using feeders, has the effect in the equation $A = \frac{1}{4n^2}\left[\frac{\rho I L^2}{3S_i}\right]$ of increasing the number by ½ a feeder. This will explain the points as the curve in Fig. 90 of ½, 1½, 2½ feeders, etc.

If the bus bar is insulated, the equation for area representing leakage current is $a = \frac{1}{12\sqrt{3}\,n^2}\left[\frac{\rho I L^2}{3S_i}\right]$

Cross-section of Copper at Power Station. Fig. 87 gives the cross-section of the copper at the power station in the several cases, to give equal weights of copper, the unit of weight being wS_iL, or a weight of copper of length L, which gives a conductivity equal to that of the rails.

Leakage Current. Fig. 88 gives the relative leakage currents for the several cases (in which the bus bar is grounded) plotted to amount of copper used. The unit of leakage current is taken as that which occurs on a line without negative copper, of which the bus bar is grounded. Fig. 89 gives the relative leakage currents with the bus bar insulated. Fig. 90 gives the relative leakage currents for Case VII with bus bar insulated, plotted with the

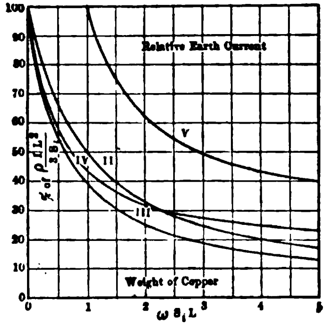


FIG. 88.—Relative earth current negative bus grounded.

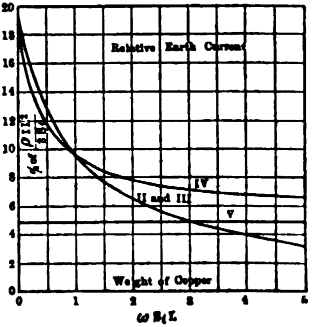


FIG. 89.—Relative earth current, negative bus insulated.

number of feeders as abscissas, the points representing half feeders being as explained above.

Negative Return System for Network. The proper negative return system for a network, such as is made up of the return paths in a city system, may be approximated by the following method: The locations of the points at which the load currents which are assumed to return to the power station are determined. The current and voltage drop in each branch of the network are then calculated and the probable amount of auxiliary conductor is then estimated and added to the network. The values of current and voltage drop in each branch of the new network thus found is calculated. The process of adjustment and calculation is continued until the voltage drops are reasonably below the limit placed for good operation, energy economy, or to provide against electrolysis or demanded by local regulation.

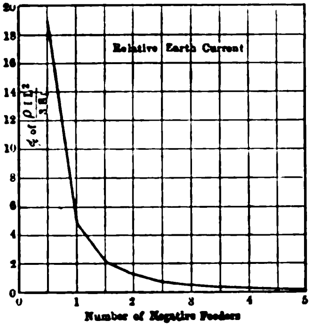


FIG. 90.—Relative earth current, negative bus insulated, Case VII.

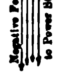
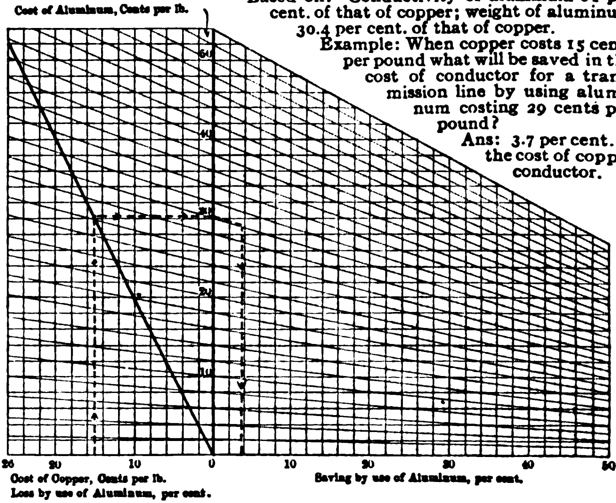


FIG. 91.—Connections between rails and negative feeders.

Connections from Track to Overhead Line.—The conductor used from the rail to manhole or foot of the pole is bare, weatherproof, or rubber covered stranded conductor, with or without lead sheath. Where the rails are in fairly good electrical contact with the earth, it is not necessary that the conductor be insulated. Where the conductor is likely to be disturbed mechanically, it may be encased in pipe. Fig. 91 shows a typical scheme of connections between rails and negative feeders. The size of the longitudinal cables will depend upon the load to be cared for, but for reliability they should be divided into at least two cables per track as shown. The number and size of cross bonds will also depend upon the load. They should be spread out along the track as shown.

Aluminum Conductor Compared with Copper Conductor. Since aluminum has a greater temperature coefficient of linear expansion, its use demands a greater height or greater number of poles or towers and greater spacing of conductors to prevent the conductors from sagging dangerously low or swinging too near together. Since aluminum weighs less it will not require such heavy supports and will cost less to string, but because it is softer more care must be taken in handling it, in order that it may not be badly scratched. Aluminum wire of the same conductivity will gather less sleet but presents a greater surface to the wind. Due to its greater radius, leakage from it is less and the skin effect is slightly greater. Because of its lower melting point, there is greater danger from arcing. The initial saving (or loss) in the use of aluminum conductor of such a size as to have a conductivity equal to that of the copper wire which would be required, may be rapidly approximated by the use of Fig. 92. The figure is manipulated as follows for the example shown: From the 15-cent point on the "Cost of Copper" scale follow the vertical to its intersection with the diagonal. Follow



Based on: Conductivity of aluminum 61 per cent. of that of copper; weight of aluminum 30.4 per cent. of that of copper.

Example: When copper costs 15 cents per pound what will be saved in the cost of conductor for a transmission line by using aluminum costing 29 cents per pound?

Ans: 3.7 per cent. of the cost of copper conductor.

FIG. 92.—Comparison of costs, copper and aluminum conductor.

the horizontal through this point to its intersection with the "Cost of Aluminum" scale. Follow the oblique through this point to its intersection with the horizontal through the 29-cent point and from this intersection follow the vertical down to the "Saving by the use of aluminum" scale. Here it is found that, *for the example shown*, the first cost of the aluminum is 3.7 per cent. less than the first cost of the necessary copper would have been.

RESISTANCE AND WEIGHT PER **Thousand Feet** OF BARE **Solid** COPPER WIRE

For one conductor at 20° C. (68° F.). [See footnote]

A.W.G. [B. & S.]	Diameter, mils	Circular mils	Copper		
			Lb. per 1000 ft.	Annealed	Hard drawn
				Ohms per 1000 ft.	Ohms per 1000 ft.
....	....	500,000	1514.0	0.02074	0.02130
....	....	400,000	1211.0	0.02593	0.02663
....	....	300,000	908.1	0.03457	0.03550
....	....	250,000	756.8	0.04148	0.04260
0000	460.0	211,600	640.5	0.04901	0.05033
000	409.6	167,800	507.9	0.06180	0.06347
00	364.8	133,100	402.8	0.07793	0.08003
0	324.9	105,500	319.5	0.09827	0.10009
1	289.3	83,690	253.3	0.1239	0.1272
2	257.6	66,370	200.9	0.1563	0.1605
3	229.4	52,640	159.3	0.1970	0.2023
4	204.3	41,740	126.4	0.2485	0.2552
5	181.9	33,100	100.2	0.3133	0.3218
6	162.0	26,250	79.46	0.3951	0.4058
7	144.3	20,820	63.02	0.4982	0.5116
8	128.5	16,510	49.98	0.6282	0.6452
9	114.4	13,090	39.63	0.7921	0.8135
10	101.9	10,380	31.43	0.9989	1.026
11	90.74	8,234	24.92	1.260	1.294
12	80.81	6,530	19.77	1.588	1.631
13	71.96	5,178	15.68	2.003	2.057
14	64.08	4,107	12.43	2.525	2.593

NOTE: Values in this table are based on Circular No. 31 of U. S. Bureau of Standards, 1914. Resistance in ohms per mil foot as follows: Annealed copper, 10.371; hard drawn copper 10.651; hard drawn aluminum 17.01. Stranded conductor values are for lay of 1 in 15.7. For any other lay, equal to 1 in n, resistance or weight may be calculated by increasing the above tabulated values by $\left(\frac{493.0}{n^2} - 2\right)$ per cent.

RESISTANCE AND WEIGHT PER Thousand Feet OF BARE Stranded COPPER AND ALUMINUM CONDUCTOR

For one conductor at 20° C. (68° F.) [See footnote, page 753]

A. W. G. [B. & S.]	Circular mils	Copper			Aluminum	
		Lb. per 1000 ft.	Annealed	Hard drawn	Hard drawn	
			Ohms per 1000 ft.	Ohms per 1000 ft.	Lb. per 1000 ft.	Ohms per 1000 ft.
	2,000,000	6180.	0.00529	0.00543	1880.	0.00868
	1,900,000	5870.	0.00557	0.00572	1780.	0.00913
	1,800,000	5560.	0.00588	0.00604	1690.	0.00965
	1,700,000	5250.	0.00622	0.00639	1590.	0.01021
	1,600,000	4940.	0.00661	0.00679	1500.	0.0108
	1,500,000	4630.	0.00705	0.00724	1410.	0.0116
	1,400,000	4320.	0.00756	0.00776	1310.	0.0124
	1,300,000	4010.	0.00814	0.00836	1220.	0.0134
	1,200,000	3710.	0.00882	0.00905	1120.	0.0145
	1,100,000	3400.	0.00962	0.00988	1030.	0.0158
	1,000,000	3090.	0.0106	0.0109	937.	0.0174
	900,000	2780.	0.0118	0.0121	845.	0.0193
	800,000	2470.	0.0132	0.0136	750.	0.0217
	700,000	2160.	0.0151	0.0155	656.	0.0248
	600,000	1850.	0.0176	0.0181	562.	0.0289
	500,000	1540.	0.0212	0.0218	468.	0.0347
	400,000	1240.	0.0265	0.0272	375.	0.0434
	300,000	926.	0.0353	0.0362	281.	0.0578
	250,000	772.	0.0423	0.0435	234.	0.0695
0000	212,000	653.	0.0499	0.0513	198.	0.0818
000	168,000	518.	0.0630	0.0647	157.	0.103
00	133,000	411.	0.0795	0.0817	125.	0.130
0	106,000	326.	0.0908	0.103	99.0	0.165
1	83,700	258.	0.126	0.130	78.5	0.207
2	66,400	205.	0.159	0.164	62.2	0.262
3	52,600	163.	0.201	0.207	49.3	0.330
4	41,700	129.	0.254	0.261	39.2	0.415
5	33,100	102.	0.320	0.328	31.0	0.525
6	26,300	81.0	0.402	0.413	24.6	0.660
7	20,800	64.3	0.509	0.522	19.5	0.835
8	16,500	51.0	0.641	0.658	15.5	1.05

Resistance and Weight per Mile of Bare Solid Copper Wire

For one conductor at 20° C. (68° F.). [See footnote, page 753]

A. W. G. (B. & S.)	Diameter, mils	Circular mils	Copper		
			Lb. per mile	Annealed	Hard drawn
				Ohms per mile	Ohms per mile
....	....	500,000	7994.	0.1095	0.1125
....	....	400,000	6394.	0.1369	0.1406
....	....	300,000	4795.	0.1825	0.1874
....	....	250,000	3996.	0.2190	0.2249
0000	460.0	211,600	3382.	0.2587	0.2657
000	409.6	167,800	2682.	0.3260	0.3351
00	364.8	133,100	2127.	0.4115	0.4227
0	324.9	105,500	1687.	0.5189	0.5280
1	289.3	83,690	1337.	0.6542	0.6716
2	257.6	66,370	1061.	0.8253	0.8474
3	229.4	52,640	841.1	1.040	1.068
4	204.3	41,740	667.4	1.312	1.347
5	181.9	33,100	529.0	1.654	1.699
6	162.0	26,250	419.5	2.086	2.143
7	144.3	20,820	332.7	2.630	2.701
8	128.5	16,510	263.9	3.317	3.406
9	114.4	13,090	209.2	4.182	4.295
10	101.9	10,380	165.9	5.274	5.417
11	90.74	8,234	131.6	6.653	6.832
12	80.81	6,530	104.4	8.385	8.612
13	71.96	5,178	82.79	10.58	10.86
14	64.08	4,107	65.63	13.33	13.69

RESISTANCE AND WEIGHT PER Mile OF BARE Stranded COPPER AND ALUMINUM CONDUCTOR

For one conductor at 20° C. (68° F.). [See footnote, page 753]

A. W. G. (B. & S.)	Circular mils	Copper			Aluminum	
		Lb. per mile	Annealed	Hard drawn	Hard drawn	
			Ohms per mile	Ohms per mile	Lb. per mile	Ohms per mile
	2,000,000	32,600	0.0279	0.0287	9930.	0.0458
	1,900,000	31,000	0.0294	0.0302	9400.	0.0482
	1,800,000	29,400	0.0310	0.0319	8920.	0.0509
	1,700,000	27,700	0.0328	0.0337	8400.	0.0539
	1,600,000	26,100	0.0349	0.0359	7920.	0.0570
	1,500,000	24,400	0.0372	0.0382	7450.	0.0612
	1,400,000	22,800	0.0399	0.0410	6920.	0.0655
	1,300,000	21,200	0.0430	0.0441	6440.	0.0708
	1,200,000	19,600	0.0466	0.0478	5910.	0.0766
	1,100,000	17,900	0.0507	0.0522	5440.	0.0834
	1,000,000	16,300	0.0560	0.0576	4950.	0.0919
	900,000	14,700	0.0623	0.0639	4460.	0.102
	800,000	13,000	0.0697	0.0718	3960.	0.115
	700,000	11,400	0.0797	0.0818	3460.	0.131
	600,000	9,770	0.0929	0.0956	2970.	0.153
	500,000	8,130	0.112	0.115	2470.	0.183
	400,000	6,550	0.140	0.144	1980.	0.229
	300,000	4,890	0.186	0.191	1480.	0.305
	250,000	4,080	0.223	0.230	1240.	0.367
0000	212,000	3,450	0.263	0.271	1050.	0.432
000	168,000	2,740	0.333	0.342	829.	0.544
00	133,000	2,170	0.420	0.431	660.	0.686
0	106,000	1,720	0.527	0.544	523.	0.871
1	83,700	1,360	0.665	0.686	415.	1.09
2	66,400	1,080	0.840	0.866	328.	1.38
3	52,600	861	1.06	1.09	260.	1.74
4	41,700	681	1.34	1.38	207.	2.19
5	33,100	539	1.69	1.73	164.	2.77
6	26,300	428	2.12	2.18	130.	3.48
7	20,800	339	2.69	2.76	103.	4.41
8	16,500	269	3.38	3.47	81.8	5.54

APPROXIMATE WEIGHT OF WEATHERPROOF COPPER CONDUCTOR
(American Steel & Wire Co.)

Size, A. W. G. (B. & S.)	Diam. bare conductor, mils	Double braid		Triple braid	
		Lb. per 1000 ft.	Lb. per mile	Lb. per 1000 ft.	Lb. per mile
		SOLID CONDUCTOR			
0000	460.0	723	3817	767	4,050
000	409.6	587	3098	629	3,320
00	364.8	467	2467	502	2,650
0	325.0	377	1989	407	2,150
1	289.3	294	1553	316	1,670
2	257.6	239	1264	260	1,370
3	229.4	185	977	199	1,050
4	204.3	151	795	164	865
5	181.9	122	646	135	710
6	162.0	100	529	112	590
8	128.5	66	349	75	395
9	114.4	54	283	62	325
10	101.9	46	241	53	280
12	80.8	30	158	35	185
14	64.1	20	107	25	130
Cir. mils		STRANDED CONDUCTOR			
2,000,000	1.6302	6,690	35,323	7,008	37,000
1,750,000	1.5246	5,894	31,119	6,193	32,700
1,500,000	1.4124	5,098	26,915	5,380	28,400
1,250,000	1.2892	4,264	22,516	4,508	23,800
1,000,000	1.1520	3,456	18,246	3,674	19,400
900,000	1.0935	3,127	16,513	3,332	17,600
800,000	1.0305	2,799	14,779	2,992	15,800
750,000	0.9981	2,635	13,913	2,822	14,900
700,000	0.9639	2,471	13,046	2,650	14,000
600,000	0.8928	2,093	11,052	2,235	11,800
500,000	0.8134	1,765	9,318	1,894	10,000
450,000	0.7721	1,601	8,452	1,724	9,100
400,000	0.7280	1,436	7,584	1,553	8,200
350,000	0.6811	1,248	6,589	1,345	7,100
300,000	0.6285	1,083	5,721	1,174	6,200
250,000	0.5735	907	4,788	985	5,200
0000	0.5275	745	3,935	800	4,220
000	0.4700	604	3,190	653	3,450
00	0.4134	482	2,544	522	2,760
0	0.3684	388	2,051	424	2,240
1	0.3279	303	1,599	328	1,735
2	0.2919	246	1,301	270	1,425
3	0.2601	190	1,004	206	1,090
4	0.2316	155	820	170	900
5	0.2061	126	668	140	740
6	0.1836	103	544	115	610
8	0.1455	68	359	78	410

ALLOWABLE CURRENT-CARRYING CAPACITY OF WIRES AND CABLES

National Board of Fire Underwriters—1913

Size A.W.G. (B. & S.) circular mils.	Rubber insulation, amperes	Other insulations, amperes
18	3	5
16	6	10
14	15	20
12	20	25
10	25	30
8	35	50
6	50	70
5	55	80
4	70	90
3	80	100
2	90	125
1	100	150
0	125	200
00	150	225
000	175	275
0000	225	325
200,000	200	300
300,000	275	400
400,000	325	500
500,000	400	600
600,000	450	680
700,000	500	760
800,000	550	840
900,000	600	920
1,000,000	650	1,000
1,100 000	690	1,080
1,200,000	730	1,150
1.300,000	770	1,220
1,400,000	810	1,290
1,500,000	850	1.360
1,600,000	890	1,430
1.700,000	930	1,490
1,800,000	970	1.550
1,900,000	1,010	1,610
2,000,000	1,050	1,670

LOADING OF BARE STRANDED COPPER CABLE ALONE, WITH ICE COAT, AND WITH ICE COAT AND WIND

Cir. mils	Strands of conductor		Diameter of cable overall, In.	Loading per lineal ft.			
	Number	Diameter, In.		Cable alone, Lb.	Cable with ½ in. ice coat, Lb.	Wind at 8 lb. per sq. ft., Lb.	Resultant cable ice, and wind Lb.
2,000,000	91	0.1482	1.630	6.180	7.518	1.729	7.719
1,750,000	91	0.1387	1.526	5.404	6.677	1.659	6.885
1,500,000	91	0.1284	1.412	4.630	5.831	1.584	6.048
1,250,000	91	0.1172	1.289	3.868	4.992	1.516	5.220
1,000,000	61	0.1280	1.152	3.090	4.128	1.425	4.370
950,000	61	0.1248	1.123	2.935	3.955	1.406	4.200
900,000	61	0.1215	1.094	2.780	3.782	1.386	4.030
850,000	61	0.1181	1.063	2.625	3.607	1.365	3.860
800,000	61	0.1145	1.031	2.470	3.432	1.344	3.688
750,000	61	0.1109	0.998	2.315	3.257	1.322	3.518
700,000	61	0.1071	0.964	2.160	3.080	1.297	3.346
650,000	61	0.1032	0.929	2.005	2.903	1.276	3.174
600,000	61	0.0992	0.893	1.850	2.725	1.252	3.003
550,000	37	0.1219	0.853	1.693	2.543	1.226	2.827
500,000	37	0.1162	0.813	1.540	2.369	1.201	2.659
450,000	37	0.1103	0.772	1.387	2.187	1.175	2.485
400,000	37	0.1040	0.728	1.240	2.011	1.153	2.318
350,000	37	0.0973	0.668	1.083	1.824	1.119	2.140
300,000	19	0.1256	0.629	0.926	1.635	1.086	1.963
250,000	19	0.1147	0.574	0.772	1.446	1.049	1.786
211,600	19	0.1055	0.528	0.653	1.299	1.018	1.630

LOADING OF TRIPLE BRAID WEATHERPROOF STRANDED COPPER CABLE ALONE, WITH ICE COAT AND WITH ICE COAT AND WIND

Cir. mils	Strands of conductor		Diameter of cable overall	Loading per lineal foot			
	Number	Diameter		Cable alone	Cable. with ½ in. ice coat	Wind at 8 lb. per sq. ft.	Resultant cable, ice, and wind
		In.	In.	Lb.	Lb.	Lb.	Lb.
2,000,000	91	0.1482	2.000	7.008	8.579	2.000	8.809
1,750,000	91	0.1387	1.906	6.193	7.705	1.937	7.945
1,500,000	91	0.1284	1.781	5.380	6.813	1.858	7.064
1,250,000	91	0.1172	1.656	4.508	5.863	1.771	6.124
1,000,000	61	0.1280	1.531	3.674	4.950	1.687	5.230
950,000	61	0.1248	1.468	3.503	4.745	1.645	4.922
900,000	61	0.1215	1.437	3.332	4.549	1.625	4.831
850,000	61	0.1181	1.406	3.162	4.360	1.604	4.645
800,060	61	0.1145	1.375	2.992	4.170	1.583	4.461
750,000	61	0.1109	1.343	2.822	3.977	1.562	4.272
700,000	61	0.1071	1.312	2.650	3.789	1.541	4.090
650,000	61	0.1032	1.250	2.443	3.543	1.500	3.847
600,000	61	0.0992	1.234	2.235	3.325	1.489	3.556
550,000	37	0.1219	1.156	2.064	3.105	1.437	3.421
500,000	37	0.1162	1.108	1.894	2.908	1.405	3.230
450,000	37	0.1103	1.062	1.724	2.705	1.375	3.035
400,000	37	0.1040	1.031	1.553	2.515	1.354	2.856
350,000	37	0.0973	0.968	1.345	2.267	1.312	2.620
300,000	19	0.1256	0.921	1.174	2.067	1.281	2.431
250,000	19	0.1147	0.875	0.985	1.849	1.250	2.232
211,600	19	0.1055	0.812	0.800	1.624	1.208	2.024

Loading of Bare Stranded Aluminum Cable Alone, with Ice Coat and with Ice Coat and Wind

Cir. mils	Number of strands	Diameter of cable overall	Loading per lineal foot			
			Cable alone	Cable, with ½ in. ice coat	Wind at 8 lb. per sq. ft.	Resultant cable, ice, and wind
		In.	Lb.	Lb.	Lb.	Lb.
1,590,000	61	1.438	1.462	2.679	1.625	3.133
1,575,500	61	1.406	1.393	2.591	1.604	3.047
1,431,000	61	1.359	1.317	2.485	1.573	2.941
1,351,500	61	1.328	1.243	2.392	1.552	2.851
1,272,000	61	1.281	1.171	2.290	1.521	2.749
1,192,500	37	1.250	1.098	2.195	1.500	2.658
1,113,000	37	1.203	1.025	2.095	1.469	2.559
1,033,500	37	1.156	0.950	1.990	1.438	2.455
954,000	37	1.109	0.877	1.888	1.406	2.354
874,500	37	1.063	0.805	1.787	1.375	2.255
795,000	37	1.016	0.732	1.684	1.344	2.155
715,500	37	0.969	0.658	1.587	1.313	2.060
636,000	37	0.906	0.585	1.469	1.271	1.943
556,500	19	0.859	0.512	1.366	1.240	1.845
477,000	19	0.781	0.439	1.244	1.188	1.720
397,500	19	0.719	0.365	1.131	1.146	1.610
336,420	7	0.656	0.310	1.037	1.104	1.515

LOADING OF TRIPLE BRAID WEATHERPROOF STRANDED ALUMINUM CABLE ALONE, WITH ICE COAT AND WITH ICE COAT AND WIND

Cir. mils	Number of strands	Diameter of cable overall	Loading per lineal foot			
			Cable alone	Cable with ½ in. ice coat	Wind at 8 lb. per sq. ft.	Resultant cable, ice and wind
		In.	Lb.	Lb.	Lb.	Lb.
1,590,000	61	1.875	2.070	3.562	1.917	4.045
1,515,500	61	1.813	1.977	3.430	1.875	3.909
1,431,000	61	1.781	1.877	3.310	1.854	3.794
1,351,500	61	1.750	1.779	3.193	1.833	3.680
1,272,000	61	1.719	1.683	3.077	1.813	3.571
1,192,500	37	1.688	1.586	2.961	1.792	3.461
1,113,000	37	1.563	1.489	2.785	1.708	3.267
1,033,500	37	1.531	1.390	2.666	1.688	3.155
954,000	37	1.500	1.293	2.550	1.667	3.047
874,500	37	1.469	1.197	2.434	1.646	2.938
795,000	37	1.438	1.100	2.217	1.625	2.749
715,500	37	1.344	0.994	2.152	1.563	2.660
636,000	37	1.250	0.886	1.983	1.500	2.486
556,500	19	1.188	0.772	1.832	1.458	2.341
477,000	19	1.031	0.657	1.615	1.354	2.107
397,500	19	1.000	0.544	1.487	1.333	1.997
336,420	7	0.938	0.460	1.363	1.298	1.882

Minimum Sags Allowable for Bare Conductor (A.E.R.E.A. Recommended Specification). In the tables, pages 763 to 765, are given the sags at which bare conductors should be strung in order that, when loaded with the specified requirement of ½ in. of ice and a wind load of 8.0 lb. per square foot of projected area at 0 deg. F., the tension in the conductor will not exceed the allowable value of the ultimate strength of the conductor. The sags given for 120 deg. F. are greater in every case than the vertical component of the sags at 0 deg. F. under the maximum wind and ice load. The physical constants of the conductor used are as follows:

Modulus of elasticity

Copper, hard drawn, solid or stranded	16,000,000
Copper, soft drawn, solid	12,000,000
Aluminum, hard drawn	9,000,000

Temperature coefficient

Copper	0.0000096
Aluminum	0.0000128

MINIMUM SAGS FOR STRANDED HARD-DRAWN BARE COPPER WIRE

Size, A.W.G. (B.&S.)	Temp. fahr.	Span, feet								
		100 or less	125	150	200	250	300	400	500	600
		Sags								
		In.	In.	In.	In.	In.	In.	Ft.	Ft.	Ft.
0000	—20	2	3	5	8	13	20.	3.5	6.	10.
	0	2	4	5	9	14	22.	3.5	6.5	10.5
	20	3	4	6	10	16	24.	4.	7.	11.5
	40	3	4	6	11	18	27.	4.5	8.	12.
	60	3	5	7	13	20	31.	5.	8.5	13.
	80	4	6	8	15	24	35.	5.5	9.	13.5
	100	4	7	10	17	27	40.	6.	10.	14.5
	120	5	8	12	20	31	46.	7.	10.5	15.
000	—20	2	3	5	8	13	21.	4.	7.	12.
	0	2	4	5	9	15	23.	4.	7.5	12.5
	20	3	4	6	10	17	25.	4.5	8.5	13.5
	40	3	4	6	12	19	29.	5.	9.	14.
	60	3	5	7	13	22	33.	6.	9.5	15.
	80	4	6	8	15	25	38.	6.5	10.5	15.5
	100	4	7	10	18	29	43.	7.	11.	16.
	120	5	8	12	21	34	49.	7.5	12.	17.
00	—20	2	3	5	9	14	23.	4.5	9.	15.
	0	2	4	5	10	16	26.	5.	9.5	15.5
	20	3	4	6	11	18	29.	5.5	10.	16.
	40	3	4	7	12	21	33.	6.	11.	17.
	60	3	5	7	14	24	37.	6.5	11.5	17.5
	80	4	6	9	16	28	43.	7.	12.	18.
	100	5	7	10	19	32	48.	8.	12.5	18.5
	120	6	9	12	23	37	54.	8.5	13.5	19.5
0	—20	2	3	5	9	16	2.5	5.5	11.5	18.5
	0	2	4	5	10	18	2.5	6.5	12.	19.
	20	3	4	6	11	21	3.	7.	12.5	19.5
	40	3	5	7	13	24	3.5	7.5	13.	20.
	60	3	5	8	15	27	4.	8.	14.	20.5
	80	4	6	9	18	32	4.5	8.5	14.5	21.5
	100	5	7	11	21	37	5.	9.	15.	22.
	120	6	9	13	25	42	5.	9.5	15.5	22.5

MINIMUM SAGS FOR HARD-DRAWN BARE COPPER WIRE

Size, A.W.G. (B.&S.)	Temp. fahr.	Span, feet								
		100 or less	125	150	200	250	300	400	500	600
		Sags								
		In.	In.	In.	In.	In.	Ft.	Ft.	Ft.	Ft.
1	—20	2	4	5	10.	19.	3.	8.	14.5	23.
	0	3	4	6	11.	22.	3.5	8.5	15.	23.5
	20	3	4	6	13.	25.	4.	9.	16.	24.
	40	3	5	7	15.	30.	4.5	9.5	16.	24.5
	60	4	6	8	18.	34.	5.	10.	17.	25.
	80	4	7	10	21.	39.	5.5	10.5	17.	25.5
	100	5	8	12	25.	44.	6.	11.	18.	26.
	120	6	10	16	30.	49.	6.	11.5	18.	26.5
2	—20	2	4	5	12.	25.	4.	10.5	18.5	29.
	0	3	4	6	14.	29.	4.5	11.	19.	29.5
	20	3	5	7	16.	33.	5.	11.5	19.5	30.
	40	3	5	8	19.	39.	5.5	12.	20.	30.5
	60	4	6	10	23.	43.	6.	12.5	20.5	31.
	80	4	7	12	27.	48.	6.5	13.	21.	31.
	100	5	9	14	31.	53.	7.	13.	21.5	31.5
	120	7	11	18	35.	58.	7.5	13.5	22.	32.
3	—20	3	4	6	17.	3.	6.	14.	24.	37.5
	0	3	4	7	20.	3.5	6.5	14.5	24.5	37.5
	20	3	5	8	23.	4.	7.	15.	25.	38.
	40	3	6	10	27.	4.5	7.5	15.	25.	38.
	60	4	7	12	30.	5.	8.	15.5	25.5	38.5
	80	5	9	14	35.	5.5	8.5	16.	26.	39.
	100	6	11	17	39.	5.5	8.5	16.5	26.	39.
	120	8	14	22	44.	6.	9.	16.5	26.5	39.5
4	—20	3	4	8	25.	5.	9.	18.	31.	46.
	0	3	5	9	29.	5.5	9.	18.5	31.5	46.
	20	3	6	11	33.	6.	9.5	19.	31.5	46.5
	40	4	7	13	38.	6.5	10.	19.	32.	46.5
	60	4	9	16	42.	6.5	10.	19.5	32.5	47.
	80	5	11	19	46.	7.	10.5	19.5	32.5	47.5
	100	7	13	23	50.	7.5	11.	20.	32.5	47.5
	120	9	16	27	54.	7.5	11.	20.5	33.	48.
6	—20	3	8	22	5.5	10.	15.	30.	.....	.....
	0	4	10	26	6.	10.	15.	30.	.....	.....
	20	5	13	30	6.	10.5	15.5	30.5	.....	.....
	40	6	16	33	6.	10.5	15.5	30.5	.....	.....
	60	8	19	36	6.5	11.	16.	31.	.....	.....
	80	10	22	39	6.5	11	16.	31.	.....	.....
	100	13	25	41	7.	11.5	16.5	31.	.....	.....
	120	16	28	44	7.	11.5	16.5	31.5	.....	.....

MINIMUM SAGS FOR STRANDED BARE ALUMINUM WIRE

Size, A.W.G. (B.&S.)	Temp. fahr.	Span, feet									
		80 or less	100	125	150	200	250	300	400	500	600
		Sags									
		In.	In.	In.	In.	In.	Ft.	Ft.	Ft.	Ft.	Ft.
0000	—20	1	2	3	5	11.	2.5	5.	11.	19.	29.
	0	1	2	3	6	15.	3.	5.5	12.	19.5	29.5
	20	2	3	5	8	21.	3.5	6.	12.5	20.5	30.
	40	2	4	7	11	27.	4.5	7.	13.	21.	31.
	60	4	6	11	17	34.	5.	7.5	13.5	21.5	31.5
	80	6	10	16	22	41.	5.5	8.	14.	22.	32.
	100	10	14	20	27	46.	6.	8.5	14.5	22.5	33.
	120	13	18	25	32	52.	6.5	9.	15.	23.	33.5
000	—20	1	2	3	5	12.	3.	5.5	13.	22.	33.5
	0	1	2	4	6	17.	3.5	6.5	13.5	22.5	34.
	20	2	3	5	8	24.	4.	7.	14.	23.	34.5
	40	2	4	7	12	31.	5.5	7.5	14.5	23.5	35.
	60	3	5	11	18	38.	5.5	8.	15.	24.	35.5
	80	6	9	16	23	43.	6.	8.5	15.5	24.5	36.
	100	10	13	20	29	49.	6.5	9.	16.	25.	36.5
	120	13	17	25	33	54.	7.	9.5	16.5	25.5	37.
00	—20	1	2	3	6	2.	5.	8.5	16.5	28.	42.
	0	2	2	4	8	2.5	5.5	9.	17.	28.5	42.5
	20	2	3	6	12	3.	6.	9.	17.5	29.	43.
	40	2	4	9	18	3.5	6.5	9.5	18.	29.5	43.
	60	4	7	14	24	4.	7.	10.	18.5	29.5	43.5
	80	7	12	19	29	4.5	7.	10.5	19.	30.	44.
	100	10	16	24	33	5.	7.5	11.	19.5	30.5	44.5
	120	14	19	28	38	5.5	8.	11.5	20.	31.	44.5
0	—20	1	2	4	9	3.5	7.	10.5	21.	36.5	.....
	0	2	3	6	14	4.	7.	11.	21.5	36.5	.....
	20	2	4	8	20	4.5	7.5	11.5	22.	37.	.....
	40	3	6	13	26	5.	8.	12.	22.	37.	.....
	60	5	10	18	31	5.	8.5	12.	22.5	37.5	.....
	80	8	14	23	35	5.5	8.5	12.5	23.	38.	.....
	100	12	18	27	39	6.	9.	13.	23.	38.	.....
	120	15	21	31	43	6.	9.5	13.5	23.5	38.5	.....
1	—20	1	3	7	20	5.	9.	13.5	26.5	43.5	.....
	0	2	4	11	25	5.5	9.	14.	27.	43.5	.....
	20	2	5	16	30	5.5	9.5	14.5	27.	44.	.....
	40	4	9	21	34	6.	10.	14.5	27.5	44.	.....
	60	7	13	25	39	6.5	10.	15.	27.5	44.5	.....
	80	10	18	29	42	6.5	10.5	15.5	28.	44.5	.....
	100	14	21	32	45	7.	11.	15.5	28.	45.	.....
	120	17	24	36	49	7.	11.	16.	28.5	45.	.....

The values of inductive reactance in the following tables are from the N. E. L. A. Handbook on Overhead Construction, 1914

INDUCTIVE REACTANCE

Ohms per 1000 Ft. (for one wire)—Solid Conductor 25 Cycles

Inter-axial distance, inches	Size of wire—A. W. G. (B. & S.)											
	0000	000	00	0	1	2	3	4	5	6	7	8
3/8	....	....	0.00926	0.01037	0.01148	0.01259	0.01370	0.01481	0.01591	0.01702	0.01813	0.01924
1/2	0.00982	0.01093	0.01204	0.01315	0.01426	0.01537	0.01648	0.01759	0.01870	0.01981	0.02092	0.02203
3/4	0.01368	0.01479	0.01590	0.01701	0.01812	0.01923	0.02034	0.02145	0.02256	0.02367	0.02478	0.02589
1	0.01644	0.01755	0.01866	0.01977	0.02088	0.02199	0.02310	0.02421	0.02532	0.02643	0.02754	0.02865
2	0.02306	0.02417	0.02528	0.02639	0.02750	0.02861	0.02972	0.03083	0.03194	0.03305	0.03416	0.03527
3	0.02691	0.02802	0.02913	0.03024	0.03135	0.03246	0.03357	0.03468	0.03579	0.03690	0.03801	0.03912
4	0.02968	0.03079	0.03190	0.03301	0.03412	0.03523	0.03634	0.03745	0.03856	0.03967	0.04078	0.04189
5	0.03181	0.03292	0.03403	0.03514	0.03625	0.03736	0.03847	0.03958	0.04069	0.04180	0.04291	0.04402
6	0.03353	0.03464	0.03575	0.03686	0.03797	0.03908	0.04019	0.04130	0.04241	0.04352	0.04463	0.04574
7	0.03501	0.03612	0.03723	0.03834	0.03945	0.04056	0.04167	0.04278	0.04389	0.04500	0.04611	0.04722
8	0.03629	0.03740	0.03851	0.03962	0.04073	0.04184	0.04295	0.04406	0.04517	0.04628	0.04739	0.04850
9	0.03742	0.03853	0.03964	0.04075	0.04186	0.04297	0.04408	0.04519	0.04630	0.04741	0.04852	0.04963
10	0.03843	0.03954	0.04065	0.04176	0.04287	0.04398	0.04509	0.04620	0.04731	0.04842	0.04953	0.05064
11	0.03933	0.04044	0.04155	0.04266	0.04377	0.04488	0.04599	0.04710	0.04821	0.04932	0.05043	0.05154
12	0.04015	0.04126	0.04237	0.04348	0.04459	0.04570	0.04681	0.04792	0.04903	0.05014	0.05125	0.05236
15	0.04230	0.04341	0.04452	0.04563	0.04674	0.04785	0.04896	0.05007	0.05118	0.05229	0.05340	0.05451
18	0.04403	0.04514	0.04625	0.04736	0.04847	0.04958	0.05069	0.05180	0.05291	0.05402	0.05513	0.05624
21	0.04551	0.04662	0.04773	0.04884	0.04995	0.05106	0.05217	0.05328	0.05439	0.05550	0.05661	0.05772
24	0.04678	0.04789	0.04900	0.05011	0.05122	0.05233	0.05344	0.05455	0.05566	0.05677	0.05788	0.05899
30	0.04892	0.05003	0.05114	0.05225	0.05336	0.05447	0.05558	0.05669	0.05780	0.05891	0.06002	0.06113
36	0.05064	0.05175	0.05286	0.05397	0.05508	0.05619	0.05730	0.05841	0.05952	0.06063	0.06174	0.06285

INDUCTIVE REACTANCE

Ohms per 1000 Ft. (for one wire) Solid Conductor 25 cycles.—*Continued*

Inter-axial distance, inches	Size of wire—A. W. G. (B. & S.)											
	0000	000	00	0	1	2	3	4	5	6	7	8
42	0.05214	0.05325	0.05436	0.05547	0.05658	0.05769	0.05880	0.05991	0.06102	0.06213	0.06324	0.06435
48	0.05339	0.05450	0.05561	0.05672	0.05783	0.05894	0.06005	0.06116	0.06227	0.06338	0.06449	0.06560
54	0.05452	0.05563	0.05674	0.05785	0.05896	0.06027	0.06118	0.06229	0.06340	0.06451	0.06562	0.06673
60	0.05553	0.05664	0.05775	0.05886	0.05997	0.06108	0.06219	0.06330	0.06441	0.06552	0.06663	0.06774
66	0.05644	0.05755	0.05866	0.05977	0.06088	0.06199	0.06310	0.06421	0.06532	0.06643	0.06754	0.06865
72	0.05727	0.05838	0.05949	0.06060	0.06171	0.06282	0.06393	0.06504	0.06615	0.06726	0.06837	0.06948
78	0.05804	0.05915	0.06026	0.06137	0.06248	0.06359	0.06470	0.06581	0.06692	0.06803	0.06914	0.07025
84	0.05875	0.05986	0.06097	0.06208	0.06319	0.06430	0.06541	0.06652	0.06763	0.06874	0.06985	0.07096
90	0.05941	0.06052	0.06163	0.06274	0.06385	0.06496	0.06607	0.06718	0.06829	0.06940	0.07051	0.07162
96	0.06002	0.06113	0.06224	0.06335	0.06446	0.06557	0.06668	0.06779	0.06890	0.07001	0.07112	0.07223
102	0.06060	0.06171	0.06282	0.06393	0.06504	0.06615	0.06726	0.06837	0.06948	0.07059	0.07170	0.07281
108	0.06115	0.06226	0.06337	0.06448	0.06559	0.06670	0.06781	0.06892	0.07003	0.07114	0.07225	0.07336
114	0.06167	0.06278	0.06389	0.06500	0.06611	0.06722	0.06833	0.06944	0.07055	0.07166	0.07277	0.07388
120	0.06216	0.06327	0.06438	0.06549	0.06660	0.06771	0.06882	0.06993	0.07104	0.07215	0.07326	0.07437
126	0.06261	0.06372	0.06483	0.06594	0.06705	0.06816	0.06927	0.07038	0.07149	0.07260	0.07371	0.07482
132	0.06305	0.06416	0.06527	0.06638	0.06749	0.06860	0.06971	0.07082	0.07193	0.07304	0.07415	0.07526
138	0.06348	0.06459	0.06570	0.06681	0.06792	0.06903	0.07014	0.07125	0.07236	0.07347	0.07458	0.07569
144	0.06389	0.06500	0.06611	0.06722	0.06833	0.06944	0.07055	0.07166	0.07277	0.07388	0.07499	0.07610
150	0.06428	0.06539	0.06650	0.06761	0.06872	0.06983	0.07094	0.07205	0.07316	0.07427	0.07538	0.07649
156	0.06465	0.06577	0.06688	0.06799	0.06910	0.07021	0.07132	0.07243	0.07354	0.07465	0.07576	0.07687
162	0.06502	0.06613	0.06724	0.06835	0.06946	0.07057	0.07168	0.07279	0.07390	0.07501	0.07612	0.07723
168	0.06536	0.06647	0.06758	0.06869	0.06980	0.07091	0.07202	0.07313	0.07424	0.07535	0.07646	0.07757
174	0.06569	0.06680	0.06791	0.06902	0.07013	0.07124	0.07235	0.07346	0.07457	0.07568	0.07679	0.07790
180	0.06602	0.06713	0.06824	0.06935	0.07046	0.07157	0.07268	0.07379	0.07490	0.07601	0.07712	0.07823

INDUCTIVE REACTANCE

Ohms per 1000 Ft. (for one wire) Solid Conductor 60 cycles

Inter-axial distance, inches	Size of wire—A. W. G. (B. & S.)											
	0000	000	00	0	1	2	3	4	5	6	7	8
3/8	....	....	0.02228	0.02494	0.02760	0.03026	0.03292	0.03558	0.03824	0.04090	0.04356	0.04622
1/2	0.02356	0.02622	0.02888	0.03154	0.03420	0.03686	0.03952	0.04218	0.04484	0.04750	0.05016	0.05282
3/4	0.03284	0.03550	0.03816	0.04082	0.04348	0.04614	0.04880	0.05146	0.05412	0.05678	0.05944	0.06210
1	0.03945	0.04211	0.04477	0.04743	0.05009	0.05275	0.05541	0.05807	0.06073	0.06339	0.06605	0.06871
2	0.05534	0.05800	0.06066	0.06332	0.06598	0.06864	0.07130	0.07396	0.07662	0.07928	0.08194	0.08460
3	0.06458	0.06724	0.06990	0.07256	0.07522	0.07788	0.08054	0.08320	0.08586	0.08852	0.09118	0.09384
4	0.07123	0.07389	0.07655	0.07921	0.08187	0.08453	0.08719	0.08985	0.09251	0.09517	0.09783	0.10049
5	0.07634	0.07900	0.08166	0.08432	0.08698	0.08964	0.09230	0.09496	0.09762	0.10028	0.10294	0.10560
6	0.08047	0.08313	0.08579	0.08845	0.09111	0.09377	0.09643	0.09909	0.10175	0.10441	0.10707	0.10973
7	0.08403	0.08669	0.08935	0.09201	0.09467	0.09733	0.09999	0.10265	0.10531	0.10797	0.11063	0.11329
8	0.08708	0.08974	0.09240	0.09506	0.09772	0.10038	0.10304	0.10570	0.10836	0.11102	0.11368	0.11634
9	0.08980	0.09246	0.09512	0.09778	0.10044	0.10310	0.10576	0.10842	0.11108	0.11374	0.11640	0.11906
10	0.09223	0.09489	0.09755	0.10021	0.10287	0.10553	0.10819	0.11085	0.11351	0.11617	0.11883	0.12149
11	0.09440	0.09706	0.09972	0.10238	0.10504	0.10770	0.11036	0.11302	0.11568	0.11834	0.12100	0.12366
12	0.09635	0.09901	0.10167	0.10433	0.10699	0.10965	0.11231	0.11497	0.11763	0.12029	0.12295	0.12561
15	0.10153	0.10419	0.10685	0.10951	0.11217	0.11483	0.11749	0.12015	0.12281	0.12547	0.12813	0.13079
18	0.10571	0.10833	0.11099	0.11365	0.11631	0.11897	0.12163	0.12429	0.12695	0.12961	0.13227	0.13493
21	0.10921	0.11187	0.11453	0.11719	0.11985	0.12251	0.12517	0.12783	0.13049	0.13315	0.13581	0.13847
24	0.11227	0.11493	0.11759	0.12025	0.12291	0.12557	0.12823	0.13089	0.13355	0.13621	0.13887	0.14153
30	0.11740	0.12006	0.12272	0.12538	0.12804	0.13070	0.13336	0.13602	0.13868	0.14134	0.14400	0.14666
36	0.12154	0.12420	0.12686	0.12952	0.13218	0.13484	0.13750	0.14016	0.14282	0.14548	0.14814	0.15080

INDUCTIVE REACTANCE

Ohms per 1000 Ft. (for one wire) Solid Conductor 60 Cycles.—*Continued*

Inter-axial distance, inches	Size of wire—A. W. G. (B. & S.)											
	0000	000	00	0	1	2	3	4	5	6	7	8
42	0.12512	0.12778	0.13044	0.13310	0.13576	0.13842	0.14108	0.14374	0.14640	0.14906	0.15172	0.15438
48	0.12814	0.13080	0.13346	0.13612	0.13878	0.14144	0.14410	0.14676	0.14942	0.15208	0.15474	0.15740
54	0.13085	0.13351	0.13617	0.13883	0.14149	0.14415	0.14681	0.14947	0.15213	0.15479	0.15745	0.16011
60	0.13327	0.13593	0.13859	0.14125	0.14391	0.14657	0.14923	0.15189	0.15455	0.15721	0.15987	0.16253
66	0.13545	0.13811	0.14077	0.14343	0.14609	0.14875	0.15141	0.15407	0.15673	0.15939	0.16205	0.16471
72	0.13745	0.14011	0.14277	0.14543	0.14809	0.15075	0.15341	0.15607	0.15873	0.16139	0.16405	0.16671
78	0.13930	0.14196	0.14462	0.14728	0.14994	0.15260	0.15526	0.15792	0.16058	0.16324	0.16590	0.16856
84	0.14099	0.14365	0.14631	0.14897	0.15163	0.15429	0.15695	0.15961	0.16227	0.16493	0.16759	0.17025
90	0.14258	0.14524	0.14790	0.15056	0.15322	0.15588	0.15854	0.16120	0.16386	0.16652	0.16918	0.17184
96	0.14405	0.14671	0.14937	0.15203	0.15469	0.15735	0.16001	0.16267	0.16533	0.16799	0.17065	0.17331
102	0.14545	0.14811	0.15077	0.15343	0.15609	0.15875	0.16141	0.16407	0.16673	0.16939	0.17205	0.17471
108	0.14676	0.14942	0.15208	0.15474	0.15740	0.16006	0.16272	0.16538	0.16804	0.17070	0.17336	0.17602
114	0.14801	0.15067	0.15333	0.15599	0.15865	0.16131	0.16397	0.16663	0.16929	0.17195	0.17461	0.17727
120	0.14918	0.15184	0.15450	0.15716	0.15982	0.16248	0.16514	0.16780	0.17046	0.17312	0.17578	0.17844
126	0.15027	0.15293	0.15559	0.15825	0.16091	0.16357	0.16623	0.16889	0.17155	0.17421	0.17687	0.17953
132	0.15133	0.15399	0.15665	0.15931	0.16197	0.16463	0.16729	0.16995	0.17261	0.17527	0.17793	0.18059
138	0.15234	0.15500	0.15766	0.16032	0.16298	0.16564	0.16830	0.17096	0.17362	0.17628	0.17894	0.18160
144	0.15332	0.15598	0.15864	0.16130	0.16396	0.16662	0.16928	0.17194	0.17460	0.17726	0.17992	0.18258
150	0.15427	0.15693	0.15959	0.16225	0.16491	0.16757	0.17023	0.17289	0.17555	0.17821	0.18087	0.18353
156	0.15517	0.15783	0.16049	0.16315	0.16581	0.16847	0.17113	0.17379	0.17645	0.17911	0.18177	0.18443
162	0.15604	0.15870	0.16136	0.16402	0.16668	0.16934	0.17200	0.17466	0.17732	0.17998	0.18264	0.18530
168	0.15686	0.15952	0.16218	0.16484	0.16750	0.17016	0.17282	0.17548	0.17814	0.18080	0.18346	0.18612
174	0.15766	0.16032	0.16298	0.16564	0.16830	0.17096	0.17362	0.17628	0.17894	0.18160	0.18426	0.18692
180	0.15845	0.16111	0.16377	0.16643	0.16909	0.17175	0.17441	0.17707	0.17973	0.18239	0.18505	0.18771

axial distance, inches	500,000	450,000	400,000	350,000	300,000	250,000	0000	000	00					
1	0.0119	0.0124	0.0130	0.0136	0.0143	0.0152	0.0160	0.0171	0.0182	0.0193	0.0204	0.0216	0.0227	0.0238
2	0.0185	0.0190	0.0196	0.0202	0.0209	0.0218	0.0226	0.0237	0.0248	0.0259	0.0270	0.0282	0.0293	0.0304
3	0.0224	0.0229	0.0235	0.0241	0.0248	0.0257	0.0265	0.0276	0.0287	0.0298	0.0309	0.0321	0.0332	0.0343
4	0.0251	0.0256	0.0262	0.0268	0.0275	0.0284	0.0292	0.0303	0.0314	0.0325	0.0336	0.0348	0.0359	0.0370
5	0.0273	0.0278	0.0284	0.0290	0.0297	0.0306	0.0314	0.0325	0.0336	0.0347	0.0358	0.0370	0.0381	0.0392
6	0.0290	0.0295	0.0301	0.0307	0.0314	0.0323	0.0331	0.0342	0.0353	0.0364	0.0375	0.0387	0.0398	0.0409
9	0.0329	0.0334	0.0340	0.0346	0.0353	0.0362	0.0370	0.0381	0.0392	0.0403	0.0414	0.0426	0.0437	0.0448
12	0.0357	0.0362	0.0368	0.0374	0.0381	0.0390	0.0398	0.0409	0.0420	0.0431	0.0442	0.0454	0.0465	0.0476
18	0.0395	0.0400	0.0406	0.0412	0.0419	0.0428	0.0436	0.0447	0.0458	0.0469	0.0480	0.0492	0.0503	0.0514
24	0.0423	0.0428	0.0434	0.0440	0.0447	0.0456	0.0464	0.0475	0.0486	0.0497	0.0508	0.0520	0.0531	0.0542
30	0.0444	0.0449	0.0455	0.0461	0.0468	0.0477	0.0485	0.0496	0.0507	0.0518	0.0529	0.0541	0.0552	0.0563
36	0.0461	0.0466	0.0472	0.0478	0.0485	0.0494	0.0502	0.0513	0.0524	0.0535	0.0546	0.0558	0.0569	0.0580
42	0.0476	0.0481	0.0487	0.0493	0.0500	0.0509	0.0517	0.0528	0.0539	0.0550	0.0561	0.0573	0.0584	0.0595
48	0.0489	0.0494	0.0500	0.0506	0.0513	0.0522	0.0530	0.0541	0.0552	0.0563	0.0574	0.0586	0.0597	0.0608
54	0.0500	0.0505	0.0511	0.0517	0.0524	0.0533	0.0541	0.0552	0.0563	0.0574	0.0585	0.0597	0.0608	0.0619
60	0.0510	0.0515	0.0521	0.0527	0.0534	0.0543	0.0551	0.0562	0.0573	0.0584	0.0595	0.0607	0.0618	0.0629
72	0.0528	0.0533	0.0539	0.0545	0.0552	0.0561	0.0569	0.0580	0.0591	0.0602	0.0613	0.0625	0.0636	0.0647
84	0.0543	0.0548	0.0554	0.0560	0.0567	0.0576	0.0584	0.0595	0.0606	0.0617	0.0628	0.0640	0.0651	0.0662
96	0.0555	0.0560	0.0566	0.0572	0.0579	0.0588	0.0596	0.0607	0.0618	0.0629	0.0640	0.0652	0.0663	0.0674
108	0.0566	0.0571	0.0577	0.0583	0.0590	0.0599	0.0607	0.0618	0.0629	0.0640	0.0651	0.0663	0.0674	0.0685
120	0.0576	0.0581	0.0587	0.0593	0.0600	0.0609	0.0617	0.0628	0.0639	0.0650	0.0661	0.0673	0.0684	0.0695
132	0.0585	0.0590	0.0596	0.0602	0.0609	0.0618	0.0626	0.0637	0.0648	0.0659	0.0670	0.0682	0.0693	0.0704
144	0.0594	0.0599	0.0605	0.0611	0.0618	0.0627	0.0635	0.0646	0.0657	0.0668	0.0679	0.0691	0.0702	0.0713
156	0.0601	0.0606	0.0612	0.0618	0.0625	0.0634	0.0642	0.0653	0.0664	0.0675	0.0686	0.0698	0.0709	0.0720
168	0.0608	0.0613	0.0619	0.0625	0.0632	0.0641	0.0649	0.0660	0.0671	0.0682	0.0693	0.0705	0.0716	0.0727
180	0.0615	0.0620	0.0626	0.0632	0.0639	0.0648	0.0656	0.0667	0.0678	0.0689	0.0700	0.0712	0.0723	0.0734

INDUCTIVE REACTANCE

Ohms per 1000 Ft. (for one conductor)—Stranded Conductor 60 Cycles

Inter-axial distance, inches	Circular mils—Size of conductor—A. W. G. (B. & S.)													
	500,000	450,000	400,000	350,000	300,000	250,000	0000	000	00	0	1	2	3	4
1	0.0286	0.0297	0.0311	0.0326	0.0344	0.0365	0.0384	0.0411	0.0437	0.0464	0.0491	0.0519	0.0545	0.0572
2	0.0445	0.0456	0.0470	0.0485	0.0503	0.0524	0.0543	0.0570	0.0596	0.0623	0.0650	0.0678	0.0704	0.0731
3	0.0538	0.0549	0.0563	0.0578	0.0596	0.0617	0.0636	0.0663	0.0689	0.0716	0.0743	0.0771	0.0797	0.0824
4	0.0604	0.0615	0.0629	0.0644	0.0662	0.0683	0.0702	0.0729	0.0755	0.0782	0.0809	0.0837	0.0863	0.0890
5	0.0655	0.0666	0.0680	0.0695	0.0713	0.0734	0.0753	0.0780	0.0806	0.0833	0.0860	0.0888	0.0914	0.0941
6	0.0696	0.0707	0.0721	0.0736	0.0754	0.0775	0.0794	0.0821	0.0847	0.0874	0.0901	0.0929	0.0955	0.0982
9	0.0790	0.0801	0.0815	0.0830	0.0848	0.0869	0.0888	0.0915	0.0941	0.0968	0.0995	0.1023	0.1049	0.1076
12	0.0855	0.0866	0.0880	0.0895	0.0913	0.0934	0.0953	0.0980	0.1006	0.1033	0.1060	0.1088	0.1114	0.1141
18	0.0948	0.0959	0.0973	0.0988	0.1006	0.1027	0.1046	0.1073	0.1099	0.1126	0.1153	0.1181	0.1207	0.1234
24	0.1014	0.1025	0.1039	0.1054	0.1072	0.1093	0.1112	0.1139	0.1165	0.1192	0.1219	0.1247	0.1273	0.1300
30	0.1065	0.1076	0.1090	0.1105	0.1123	0.1144	0.1163	0.1190	0.1216	0.1243	0.1270	0.1298	0.1324	0.1351
36	0.1107	0.1118	0.1132	0.1147	0.1165	0.1186	0.1205	0.1232	0.1258	0.1285	0.1312	0.1340	0.1366	0.1393
42	0.1143	0.1154	0.1168	0.1183	0.1201	0.1222	0.1241	0.1268	0.1294	0.1321	0.1348	0.1376	0.1402	0.1429
48	0.1173	0.1184	0.1198	0.1213	0.1231	0.1252	0.1271	0.1298	0.1324	0.1351	0.1378	0.1406	0.1432	0.1459
54	0.1200	0.1211	0.1225	0.1240	0.1258	0.1279	0.1298	0.1325	0.1351	0.1378	0.1405	0.1433	0.1459	0.1486
60	0.1225	0.1236	0.1250	0.1265	0.1283	0.1304	0.1323	0.1350	0.1376	0.1403	0.1430	0.1458	0.1484	0.1511
72	0.1267	0.1278	0.1292	0.1307	0.1325	0.1346	0.1365	0.1392	0.1418	0.1445	0.1472	0.1500	0.1526	0.1553
84	0.1302	0.1313	0.1327	0.1342	0.1360	0.1381	0.1400	0.1427	0.1453	0.1480	0.1507	0.1535	0.1561	0.1588
96	0.1332	0.1343	0.1357	0.1372	0.1390	0.1411	0.1430	0.1457	0.1483	0.1510	0.1537	0.1565	0.1591	0.1618
108	0.1360	0.1371	0.1385	0.1400	0.1418	0.1439	0.1458	0.1485	0.1511	0.1538	0.1565	0.1593	0.1619	0.1646
120	0.1383	0.1394	0.1408	0.1423	0.1441	0.1462	0.1481	0.1508	0.1534	0.1561	0.1588	0.1616	0.1642	0.1669
132	0.1405	0.1416	0.1430	0.1445	0.1463	0.1484	0.1503	0.1530	0.1556	0.1583	0.1610	0.1638	0.1664	0.1691
144	0.1425	0.1436	0.1450	0.1465	0.1483	0.1504	0.1523	0.1550	0.1576	0.1603	0.1630	0.1658	0.1684	0.1711
156	0.1443	0.1454	0.1468	0.1483	0.1501	0.1522	0.1541	0.1568	0.1594	0.1621	0.1648	0.1676	0.1702	0.1729
168	0.1460	0.1471	0.1485	0.1500	0.1518	0.1539	0.1558	0.1585	0.1611	0.1638	0.1665	0.1693	0.1719	0.1746
	0.1476	0.1487	0.1501	0.1516	0.1534	0.1555	0.1574	0.1601	0.1627	0.1654	0.1681	0.1709	0.1735	0.1762

Preservative Treatment of Poles, Cross-arms and Ties

The following notes on wood preservation are from the Manual of the American Railway Engineering Association and the National Electric Light Association's Handbook on Overhead Line Construction, in which the bulletins of the Forest Service of the U. S. Department of Agriculture are freely quoted.

Seasoning. Various precautions to be observed in the seasoning of pole and cross-arm timber may be summarized as follows: 1. Poles should be cut from sound standing timber. 2. The bark should be well peeled from poles which are to be seasoned, and particularly from those that are to be treated, as the inner bark offers much resistance to the impregnating fluid, and in time this bark peels, leaving the untreated wood exposed to the attack of fungi. 3. Care should be taken in the handling and felling of trees, as those which are split in felling, or are otherwise roughly handled, may afterward experience serious checking. 4. As soon after cutting as possible, poles and cross-arms should be properly piled and stored, to allow free circulation of air. 5. The amount of shrinkage during seasoning is negligible. 6. Poles cut in the winter or spring have before them the best period for seasoning, but late fall and winter offer the best conditions for cutting. 7. Attention should be paid to the value of having wood seasoned where cut, as a material freight-saving may often be made in this way.

Wood Preservation. The growing scarcity of timber has led many of the railroad companies to install plants for wood preservation for the treatment of ties and timber for structural purposes. The Manual of the American Railway Engineering Association recognizes creosote oil and zinc chloride as effective wood preservatives when properly applied and when used under proper conditions. To secure successful treatment, the timber should be properly grouped as to species, proportion of heartwood and sapwood, and condition with respect to moisture. Most woods can be best treated after being air-seasoned.

In operating with zinc chloride, the strength of the solution should be varied from time to time to conform with the conditions of the wood, so as to inject the required quantities, but in no case should the strength exceed 5 per cent. Ties should dry for some time before they are put in track, to harden the outer surface. This is preferably done in piles arranged to secure drying without checking. It is recommended that certain sections of track be selected for making accurate tests covering the life of treated and untreated ties of various kinds of timber and under different treatments rather than to attempt to keep records of all ties in track. The ties inserted in this test section should be marked with dating nails. In order to judge of the penetration, borings should be made in not less than six ties in each cylinder load, and holes should be plugged with creosote turned plugs. All material should be framed and holes bored as far as possible before treatment.

For creosote oil, the specifications call for the best obtainable grade of coal-tar creosote, free from other oils, tars or substances foreign to pure coal-tar. The specific gravity, temperature at which it is completely liquid, distillate, etc., are specified, as is also the apparatus for performing the tests. The general requirements of the specifications for the treatment state that ties should not be treated until air-seasoned. The method of piling green ties is specified, and the suggestion made that it is best to determine by experiment the weight per cubic foot at which each class will best receive treatment, and then to weigh for treatment, being careful not to allow overseasoning or deterioration. Ties treated in the same run should be as nearly as possible uniform in character of timber and degree of seasoning. They should be separated into groups according to permeability as ascertained by experiment, and no ties should be put into cylinders which do not conform to the requirements as to shakes, checks, etc. If ties are thoroughly air-seasoned, a vacuum not less than 24 in. of mercury should be maintained for at least 10 minutes, after which the preservative should be admitted without breaking the vacuum. When ties not thoroughly seasoned are to be treated with metallic salts, the ties should be placed in cylinders, the door closed and live steam admitted at such a rate as to secure 20 lb. of steam pressure within 30 to 50 minutes the pressure to be maintained from 1 to 5 hours, depending upon the condition of the timber, but the pressure at no time should be allowed to exceed 20 lb. During steaming, a vent should be kept open at the bottom to permit the escape of air and condensed water from the cylinder.

When ties which are not seasoned must be treated with creosote, either long steaming or seasoning in hot creosote oil within safe limits of heat must be resorted to. When the steaming is completed the steam should be blown off and a vacuum of not less than 24 in. produced, if at sea level, or a corresponding value if above sea level, the vacuum to be maintained for at least ½ hour and the preservative admitted without breaking the vacuum.

For zinc-chloride treatment, the amount injected should be equivalent to ½ lb. of dry soluble zinc chloride per cubic foot of timber. The solution should be as weak as can be used and still obtain the desired absorption; it should not be stronger than 5 per cent. The cylinder should be entirely filled with perservative at a temperature of at least 140 deg. and maintained full while the pressure is on, an air vent being provided for releasing the air coming from the charge. Zinc chloride should be slightly basic and free from free acid.

For the zinc-tannin treatment the zinc-chloride injection should be the same as for the zinc-chloride treatment. After this the ties should be allowed to drain for 15 minutes, and 2 per cent. solution of tannic acid, made by mixing 6⅔ lb. of 30 per cent. extract of tannin with 100 lb. of water, run in and a 100-lb. pressure maintained ½ hour. This should then be run off and a 1 per cent. solution of glue admitted to the cylinder and a 100-lb. pressure maintained for ½ hour.

For plain creosoting, the creosote oil should be heated to a temperature of not less than 160 deg. and maintained at this temperature during injection. The cylinder should be entirely filled with preservative, an air vent being used to remove the air coming from the charge. At least once during each week samples of oil should be taken from the cylinder during the treatment and the water in the oil determined. If it exceeds the specified amount, a correspondingly greater quantity shall be injected; the excess being limited to 6 per cent.

In the zinc-creosote emulsion treatment an emulsion of zinc chloride and creosote oil, the latter being at least 10 per cent. of the whole, should be admitted and pressure maintained until the desired absorption is obtained. This amount should be sufficient to leave in the wood an equivalent of 5/10 lb. of dry soluble zinc chloride and 1¼ to 1½ lb. of creosote per cubic foot. The creosote oil used should be as nearly as possible of the same specific gravity as the zinc-chloride solution. It should preferably contain a large percentage of tar acids and a small percentage of naphthalene. An effective stirring apparatus must be used in the storage tank and preferably also in the cylinder.

For the two-injection zinc-chloride treatment 3/10 lb. of zinc chloride per cubic foot is first injected. The zinc chloride is then run out and creosote oil is injected to the amount of 3 lb. per cubic foot. The temperature for injection is 140 deg. for all the methods except the plain creosote, and the pressure 100 lb. except where the quantity of antiseptic is specified. The zinc-chloride process is low in first cost, and satisfactory in a dry climate. The glue and tannin are added to prevent the zinc chloride from leaching out; the creosote may be considered as added for the same purpose, or the zinc chloride may be considered as added to the creosote to reduce cost.

Creosoting is the standard method for bridge timber and its use for ties is increasing. The quantity varies from 6 to 12 lb. of creosote oil per cubic foot for ties, to 10 to 20 lb. for timber and piling.

The choice of the proper preservative is dependent, in a great measure, upon local conditions. Full-cell treatments, with a high-grade creosote oil, will insure the maximum protection, but it is by no means uncertain that full-cell treatments with petroleum oil or other heavy oils will not offer an equal amount of protection. The chief danger in employing such oil would lie in not using it in quantities sufficient to keep out moisture or air. It would seem that an entirely satisfactory oil, having antiseptic qualities, can be obtained from the distillation of water-gas tar, and as this material may be readily obtained, its general use would do much toward solving the difficulty of obtaining suitable oils at a reasonable cost. While from a theoretical standpoint the use of metallic salts cannot be recommended for poles and cross-arms on account of their solubility, still, in view of the exceptional results obtained in Germany by the use of copper sulphate and mercuric chloride, it is impossible to say that these cannot, at times, be used to great advantage. It is recommended, however, when salt treatments are employed, that they be protected against leaching by creosote or some such similar method, and also that due caution be exercised in choosing this method of treatment.

Since much of the treating which will be done by electric railway companies is likely to be by the open-tank process, special attention should be paid to specifications covering suitable oils, it being remembered that a large part of the oil distilling under 200 deg. C. is likely to be lost by volatilization during the process of treatment, thus greatly increasing the cost. The oil to be used in the open tank should constitute the higher boiling portions of the tar.

Preservative Processes

General. There are several causes underlying the rapid development which has resulted in the modern, highly efficient processes for impregnating timber with preservatives. The most important, perhaps, was the early recognition of the fact that, however great might be the value of a preservative in retarding or preventing decay, from a theoretical standpoint, its practical efficiency was likely to be largely dependent upon the extent to which it was driven into the timber. For this reason, the early methods of steeping the timber in the cold preservative contained in an open tank or vat was soon almost entirely superseded by processes insuring deeper penetration. Another important factor underlying this development was the growing demand made upon commercial plants for treated timber, coincident with the recognition of the great economic value of timber preservation and the urgent necessity for husbanding the diminishing supply of timber suitable for railroad and other purposes.

As in other branches of business, increased demand on the part of the consumer resulted in increased effort on the part of the treating plants to turn out a maximum amount of satisfactory work in the shortest possible time, while reducing the cost to a minimum. The greatest aid in the achievement of this end has been the employment of artificial pressure in injecting the fluid, it being found that by its use deep penetration could be gotten in a comparatively short time.

Owing to the heavy cost of installing high-pressure systems, however, there are comparatively few privately operated plants in the United States, and for this reason the small consumer of treated timber must either purchase from the large commercial plants, often so remote as to make the cost almost or quite prohibitive, or treat locally by a less costly process. To meet the demands of this class, as well as those who desire only a moderate protection at a small cost, the United States Forest Service has devoted considerable time to the development of the open-tank or low-pressure system, and has brought its efficiency to such a degree that in many instances it is possible to obtain adequate protection at a very low cost. Such plants can usually be operated by unskilled labor, require no expensive apparatus, and involve a very small initial investment.

All processes for treating timber may be considered under three heads—high artificial pressure systems, the atmospheric pressure systems, and the low artificial pressure systems; the first including most of the commercial plants, the second and third, the small individual plants.

High Artificial Pressure Processes. High-pressure processes may be either full cell or empty cell, depending upon whether or not the full amount of preservative injected into the timber is left in the cells or a portion subsequently withdrawn. The advocates of the full-cell treatments claim that unless the full amount of the preservative is left in the timber, sufficient protection against decay will not be afforded; while the advocates of the empty-cell treatments claim that, provided the penetration is deep, it is only necessary to leave a thin coating of the preservative on the cell-walls. Obviously, empty-cell treatments result in considerable economy of the preservative. The most prominent of the full-cell processes are the Bethell, Burnett, Card, Allardyce, Wellhouse, and Rütgers. Of the empty cell processes, the Rüping and Lowry are the best known.

Full-cell Treatments—*Bethell.* The best known of all preservative systems is the full-cell Bethell, employing straight creosote as the preservative. In operating the Bethell process, the timber to be treated is loaded upon trucks and run into a cylinder capable of withstanding a high pressure. These cylinders, or retorts, as they are now called, are sometimes as much as 9 ft. in diameter and 165 ft. long. They are made of boiler plate and are provided with doors which may be hermetically sealed and are tight under a high pressure. For light treatment, the timber may be only air seasoned, but when a heavy treatment is desired the timber is steamed after it is put into the cylinder. The method of operation is as follows: After the doors are closed, live steam is admitted and a pressure of about 20 lb. per square inch is maintained for several hours, the exact time depending upon the individual opinion of the operator as well as upon the moisture content and the size of the timber being treated. In some cases the steam pressure is allowed to go considerably above 20 lb., but much above this there is constant danger of injuring the timber. When the steam is finally blown out of the cylinder, a vacuum is created and as much of the air as possible is exhausted from the cylinder and from the wood structure. The condensed steam and sap from the wood are drawn off at the same time. The exhaustion period varies with the extent of the treatment. Finally, after a sufficient vacuum is obtained, the creosote oil is run into the cylinder and the pressure pumps are started and continued until the desired amount of preservative fluid has been injected. The remaining oil is then forced back into the storage tanks. The timber is allowed to drip for a few minutes and finally the cylinder doors are opened and the treated timber withdrawn. The whole cycle of operation takes from 6 to 20 hours, depending upon the condition and kind of timber, size of treating cylinder, quantity of injection, etc. As a rule, it requires about 3½ hours for steaming, about 1 hour for vacuum and whatever time it may be necessary to get the required injection.

Burnett. The Burnett process is similar to the Bethell, but, instead of using creosote as the preservative, it employs a 2 to

3 per cent. solution of zinc chloride, which is injected into the timber under pressure in the same way. The use of zinc chloride, or "Burnettizing," for treating railroad ties dates from 1850.

Wellhouse. The users of the Wellhouse process claim to have overcome the chief objection of the Burnett system; namely, the solubility of zinc chloride and the consequent danger of its being dissolved out of the timber when it is put into use. To prevent this the zinc-chloride treatment is followed by an injection of glue and tannin, which forms an insoluble "leather" stopping up the wood pores.

Rütgers. This is another method of preventing the leaching of the zinc chloride. A mixture of zinc chloride and creosote is employed consisting of from 15 to 20 per cent. creosote and a 3 to 4 per cent. solution of zinc chloride. The emulsion is forced into the timbers, as in the Burnettizing and Bethell processes. This system is extensively used in Europe, and to some extent in this country.

Card. This process substitutes creosote oil for the glue and tannin of the Wellhouse process, it being claimed that the oil is effective in preventing the zinc chloride from being dissolved out. The chief difference between this process and the Rütgers is that during the time of injecting the liquid into the timber the mixture is kept in continuous circulation by means of a centrifugal pump. It is claimed that this precludes the possibility of a separation of the zinc chloride and creosote, and insures a uniform injection of the preservatives. The following statement is made by the exploiters of the Card system concerning its operation and efficiency:

"In the zinc-creosote or mixed treatment, as it is sometimes called, the light oils, such as phenols and cresols, to a certain extent, are soluble in hot water and are carried with the zinc chloride into the heartwood of the timber as well as through the sapwood. The heavy oils will not penetrate the heartwood but are deposited in the sapwood, and as these heavy oils are insoluble in water they prevent the zinc chloride from leaching out of the timber. The two solutions are kept constantly mixed while under pressure by means of a centrifugal pump attached to the treating cylinder; the suction to this pump is connected to the top of the cylinder, in the middle and at each end, and the discharge from the pump enters the bottom of the cylinder, and is distributed the entire length of the cylinder through a perforated pipe. The mixing device works under the same pressure that is applied to the treating cylinder. The appliance for mixing the emulsion can be applied to any kind of cylinder and is inexpensive in its first cost, operation and maintenance. Since its installation at the several plants now using the zinc-creosote process, the contention by some that the creosote and zinc solution cannot be mixed is proven to be without foundation, as all samples drawn from different parts of the retorts, and at all times during the process of treating, show the oil and solution to be in the exact proportions intended. A water solution of chloride of zinc has greater penetrating powers than creosote oil, and therefore it can easily be injected under pressure throughout the heartwood of timber."

This description serves well to illustrate the principles underlying the processes employing the zinc-chloride and creosote combination. All of them are operated under the theory that the creosote will serve as a plug to hold in the zinc chloride.

Allardyce. The Allardyce process also employs creosote and zinc chloride, but in this method of treatment the zinc chloride is first injected and then followed by a separate treatment of creosote amounting to about 1 to 3 lb. per cubic foot. The advocates of this process claim that inasmuch as the creosote oil follows the zinc chloride, a more effective protection is offered against leaching out of the salt, the creosote acting as a plug.

Empty-cell Treatment. *Rüping.* The Rüping process aims to secure protection against decay with a comparatively small quantity of creosote. Only thoroughly air-seasoned timber can be used in this process, because its successful operation depends upon compression of the air in the wood-cells. The preliminary steaming and vacuum as carried out in the Bethell process are therefore omitted. After the timber has been placed in the cylinder and the doors are closed, it is subjected to an air pressure of about 75 lb., which compresses the air contained in the cells. Still holding this pressure, the creosote is forced into the cylinder at a higher pressure, and after the timber has been well covered with the preservative, the pressure is increased to about 225 lb. This increased pressure forces the oil into the wood-cells. Then the pressure is released and the expansive force of the compressed air within the wood forces out a part of the oil and leaves merely a coating of the preservative on the cell-walls. The surplus oil is then run back into the storage tank. The expulsion of the surplus oil may be increased by a vacuum in the treating cylinder.

Lowry. As in the Rüping process, the timber is seasoned before treatment, but no compressed air is employed in injecting the preservative. As soon as the cylinder is closed, the oil is admitted and forced into the timber by pressure. Then the oil is run out of the cylinder, and a high vacuum is quickly drawn. It is claimed that the sudden expansion of the air, which has been compressed in the wood-cells, drives out the surplus oil, and that a deep penetration but light treatment is thereby given to the timber.

Atmospheric Pressure Processes. It is possible by means of some of the modifications of the atmospheric or low-pressure systems to effect full-cell or empty-cell treatment as in the high-pressure systems. Such treatments cannot be given with the same degree of facility or with the same effectiveness as with the high-pressure systems, but in many instances the treatment is adequate.

Full-cell Treatments—Steeping in Cold Preservatives. The simplest form of non-pressure full-cell treatments, if such a term can be applied to a process usually giving only superficial treatment, is the cold-steeping or soaking process extensively employed in the early days of wood preservation and used to some extent at the present time. The timber to be treated is placed in an open vat and covered with the cold solution, which may be mercuric chloride, zinc chloride, copper sulphate, or creosote oil, as the case may be. In using mercuric chloride, it is necessary to employ nonmetallic steeping pits on account of the corrosive action of the mercury. This treatment has proven very effective in preserving timber, though in this country its use for line timber has been confined almost entirely to the New England States, where some electric companies used kyanized cross-arms.

Hot or Boiling Treatments. Timber is sometimes treated by simply boiling it in the preservative contained in an open tank or closed retort for varying lengths of time. The preservative most commonly used in this process is a heavy creosote oil. The Forest Service reports that the following method is used on the Pacific coast for Douglas fir, which is an exceedingly difficult wood to treat. The timber, usually green, is placed in a treating cylinder containing creosote heated to a temperature slightly above the boiling point of water. This hot bath is continued for a time varying from several hours to 2 days or more. The duration of treatment depends upon the size and condition of the timber. During the bath much of the water contained in the sap is driven off together with the volatilized light oils. These vapors are caught in a condenser, the water separated, and the oil then run back into the receiving tank to be used over again. Finally, an oil pressure of from 100 to 125 lb. is applied, and at the same time the temperature of the oil is allowed to fall, thus forcing the preservative into the timber. This practice is subject to the general objection that it is unwise to treat timber before it has had time to dry out in the open air. It is evident that the efficiency of the process is much enhanced by the final application of pressure, and that simply boiling in an open tank is very unsatisfactory and inefficient.

The following is the method used by Mr. Martin Schreiber, Engr. Maintenance of Way, Public Service Railway Co., New Jersey, in the preservative treatment of ties, poles and cross-arms. Carbolineum is used exclusively. This treatment is applied to long leaf, sound and square edge yellow pine ties, the ties being previously seasoned for approximately 100 days after arrival at the Passaic Wharf, Newark, N. J. The open tank used is of the following dimensions: 30 ft. long by 10 ft. wide by 2 ft. deep, the oil being heated by means of steam coils in the bottom of the tank, through which a temperature of from 212 to 240 deg. F. is obtained. The ties are placed on an endless chain conveyor and passed through the oil in the tank. This requires about 15 minutes, the ties receiving a penetration of ⅛ to ³⁄₁₆ in., thereby obtaining a complete fungi resisting zone around the tie. Cross-arms are treated by dipping them into a smaller tank 14 ft. long by 3 ft. deep by 3 ft. wide, and the arms are only immersed for a period of 5 minutes, obtaining a penetration of about ¹⁄₁₆ in. Only the butts of chestnut poles are dipped. The treatment covers a distance of at least 2 ft. above the ground line. This is because the main trouble is encountered at the ground line or a few inches above or below it. The yellow pine poles are treated their entire length with creosote oil under pressure.

Alternate Hot and Cold Treatment. This process is usually carried out in an open tank, and it is the one generally known as the "**Open-tank System.**" However, in some situations it has been found advisable to employ, in carrying out the process, a low, artificial pressure, which necessitates, of course, a closed tank or retort. The wood is first treated with oil brought to a temperature of from 180 to 220 deg. F., for a sufficient length of time to heat the wood uniformly to the temperature of the preservative. It is then either changed to another bath containing cold preservative or the hot preservative is drawn out and replaced by a charge of cold preservative at or below atmospheric temperature; or the timber may be allowed to remain in the heated oil, heating being stopped and the oil permitted to cool down. The theory underlying the successful operation of any of these modifications is that the preliminary heating expands the air in the wood-cells, and when the cold oil is introduced the sudden contraction creates a partial vacuum which draws in the oil. In some instances, exceedingly good penetration has been obtained by this method, but it is not applicable to all classes of wood, owing to the variations in their penetrability.

The simplest equipment for the treatment of poles and cross-arms by the open-tank method consists of a tank, about 8 ft. deep, set high enough above the ground to permit a fire beneath it. Facilities should be provided for the convenient handling of the poles. Where steam is available, it may be used to advantage to heat the liquid by means of a coil in the tank and also to operate a hoisting engine for handling the poles. The liquid may be pumped from the treating tank to make room for the cold oil to be introduced from another tank, or two treating tanks may be employed, one for the hot treatment and one for the cold. In connection with its California experiments, the Forest Service described a pole-treating plant having a capacity of 120 poles per day, which was estimated to cost between four and five thousand dollars; or a plant with a capacity of fifty poles per day, estimated to cost two thousand dollars. The latter equipment was to consist of one 12,000-gal. iron storage tank, two 5-ft. by 8-ft. treating tanks, one 60-ft. mast with 16-ft. boom derrick, a small hoisting engine, a 20-h.p. boiler, steam coils for heating the treating tank, and one steam oil pump, capacity 2000 gal. per hour.

Open Tank. Empty-cell Treatment. In the full-cell treatment with creosote oil, the timber is removed from the tank with a considerable amount of oil on its surface. This is objectionable, not only on account of the waste of oil, but also because of the subsequent dripping of the oil from the poles and cross-arms after they have been installed. This difficulty is said to be overcome by taking a third step in the open-tank treatment before described. Before removing the timber, after the cold bath, it is reheated to 200 deg. F. for a period of from 2 to 3 hours. The same result may be accomplished by taking the timber out of the bath in the second stage of the process, after the creosote has cooled down through a range of 20 deg. F. This causes the contracting air in the wood to draw in the free oil from the surface. This method gives about the same penetration as the full-cell open-tank process, but saves a considerable quantity of oil, and moreover, leaves the surface of the wood dry.

Low Artificial Pressure Systems. The Forest Service has recently endeavored to combine the advantages of both the pressure and non-pressure processes in a low-pressure system. The seasoned timber is first treated in a hot bath, as in the non-pressure system, then it is subjected to a cold bath; but, instead of depending entirely upon the atmospheric pressure to force the preservative into the wood, some artificial pressure is also applied. The low-pressure process cannot, of course, be used with an open tank, and requires, preferably, a closed cylinder, as in high-pressure work. The advantage claimed for this method is that it requires much less time for treatment than in the open tank, and a greater absorption and a deeper and more uniform penetration are secured.

In the treating plant of the Philadelphia and Reading Coal and Iron Co., where a closed retort is used for treating mine timber, the timber is run into a cylinder on small buggies, and the doors are then closed and sealed as in the high-pressure system. Steam coils heat the preservative to 220 deg. F. After the hot bath, which is continued according to the condition and size of the wood, the hot preservative is drawn off to the lower tank. Cold oil or zinc chloride is then introduced into the treating cylinder from the storage tank. A small pump is used to pump the oil back to the storage tank and sometimes this pump is employed to produce a low pressure in the treating cylinder.

Miscellaneous Treatments. *Brush Treatments.* Applying the preservative by means of a brush is the most common, but the least efficient, of all treatments. For good results it is essential that the timber be thoroughly seasoned, and that the wood be dry at the time of treatment. The preservative is usually kept heated to about 200 deg. F. and is applied to the wood with a suitable brush. Care should be taken to fill all checks, knot-holes, and abrasions. A second coat should be applied after an interval of not less than 24 hours. Besides treating the butt of the pole, the roof of the pole and cross-arm gains should not be overlooked, as such cuts, if left unprotected, expose the interior to decay. Some companies report that they apply the preservative with a spraying machine, claiming it has decided advantages over the brush method in that it requires less labor and better fills all cracks.

Brush Combined with Open Tank. A combination of open-tank and brush treatments is made by first treating the timber with zinc chloride in an open tank, then giving it one or more brush applications of creosote or heavy tar oil.

Jacket or Butt Settings. Poles are sometimes set in shells of concrete. It is questionable whether this preserves the pole other than in a mechanical way by giving greater stability. When the concrete hardens, it contracts and may leave a space around the pole, where moisture may collect and cause the wood to decay. Some operators surround the pole with a heavy band of pitch or tar. This is not as desirable as the concrete, because it does not add to the mechanical strength of the pole setting, and has been known to create rather than prevent decay. Mention may be made here of a patented process making use of a jacket of asbestos and asphaltum placed around and at 1 or 2 in. from the pole near the ground line. The jacket has a cement bottom and is filled with a mixture of hydrated lime, chloride of sodium, copper sulphate and sand. Over the top of the jacket and surrounding the pole a reinforced cement cap is placed. It is claimed that the chemicals are held in a tight compartment, from which they are slowly dissolved and drawn into the pole.

Such descriptions might be continued indefinitely until the simplest form of pole preservation or butt reinforcement were reached, such as the method employed by a large telephone company, which may be described as follows: When the pole butts are found to be in a fairly advanced stage of decay, a stub, having about the same dimensions as the pole butt, is placed in the ground alongside of the pole. This stub is long enough to extend from the bottom end of the pole to a point about 2 ft. above the ground line. It is secured to the pole butt and to the pole above the ground either by wrappings of heavy wire or by through-bolts, or a more stable job may be made by combined wrapping and bolting. This plan could scarcely be carried out under city or town conditions, as the unsightliness of the stub would be a serious objection, but it might be followed successfully on trunk lines which pass through sparsely settled territory. There seems no reason why the upper part of poles, particulary of the harder species of wood, should not be used indefinitely provided always that the butt reinforcement is made as strong and reliable as would be the continuous pole.

SECTION XI

SIGNALS AND COMMUNICATION

The requisites of signals on an electric railway vary with many conditions; whether the system is double or single track; whether it is a city, suburban or interurban system; whether the track is straight or has many curves; whether the track is level or has many grades; speed, headway and braking possibility of trains; and whether direct current or alternating current is used to propel the trains. The selection of proper signal apparatus and arrangement for a given system, therefore, calls for an individual study of that particular system. Development due to such studies has produced a great many types and varieties of signal apparatus.

Block System. The methods and rules by means of which the movements of a train on a section of track are controlled relative to the movements of another train or other trains on the same track and section constitute a block system.

Block. A section of track the use of which by trains is thus controlled constitutes a block.

Block Signal. A block signal is a signal which controls the use of a block.

Home Block Signal. A home block signal is a signal which controls trains entering and using a block.

Distant Block Signal. A distant block signal is a signal used in connection with the home block signal to regulate the approach of a train to that home block signal.

Signal Location and Arrangement. The most important features influencing the location of signals are: (*a*) Maximum braking distance of trains as affected by their speed and weight and by the grades encountered; (*b*) location of sidings, stations, curves and like physical features of the right-of-way; (*c*) headway of trains to maintain the schedule; (*d*) the distance at which signals can be easily read and interpreted.

Signals are usually, where possible, placed upon the right-hand side of the track looking in the direction of the traffic which they govern.

Curve Protection. (Fig. 1.) Signal 1 governs west-bound cars and Signal 2 east-bound, the dangerous or obscured track lying between the two signals. The dotted lines show the control limits of the two signals, or, in other words, the extent of the track which controls the signals. A car anywhere between Signal 2 and point 3 will cause Signal 2 to remain in the "Stop" indication, while

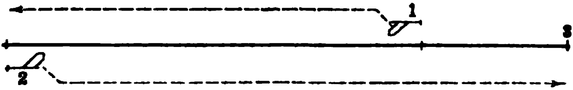


FIG. 1.—Curve protection.

Signal 1 is affected only when the car is between Signals 1 and 2. Should two following cars approach a protected curve close together, the second car would be stopped by the signal until the first car had passed beyond the limits of control of that signal.

Preliminary. Were Signal 2 controlled only up to Signal 1, it would then be possible for two cars to simultaneously pass Signals 1 and 2, each receiving a proceed indication. This may be avoided by the use of a setting section, or *preliminary*, extending beyond one of the Signals, as 1–3. This preliminary section should not ordinarily be less than 1000 ft. in length and a length of 1500 ft. is preferable. By the use of this preliminary a car running west sets Signal 2 to stop after passing point 3, and in case an east-bound car has not already passed Signal 2, it would be stopped by it. In case, however, the east-bound car had passed Signal 2 before the one west bound passed point 3, Signal 1 would be set to stop, being controlled to Signal 2, and the west-bound car would be stopped at Signal 1. The fact that Signals 1 or 2 are in the proceed indication gives the governed car the right to proceed only up to the opposing signal, or through the block, for if, as in the last-mentioned case, an east-bound car passes Signal 2 before the west-bound car passes point 3, the latter will stop at Signal 1 and the opposing car, having had a proceed signal at 2, might meet with an accident. If a preliminary were used on both ends, or the control of each signal were extended out beyond the other, two opposing cars might get into the preliminary sections at the same time. In this event both signals would assume the stop indication and neither car could proceed. It is therefore desirable to locate the signals, in a case of this kind, at least within braking distance from the point of curve so that if one car is standing at a signal an opposing car rounding the curve will be able to stop before reaching the signal.

Intermediate Signals. (Fig. 2.) Where the use of a preliminary (see preceding paragraph) is prevented, intermediate signals are sometimes used. The purpose of these intermediate signals (1 and 4) is to afford protection if two trains running in opposite directions should happen to pass points 2 and 3 at the same time.

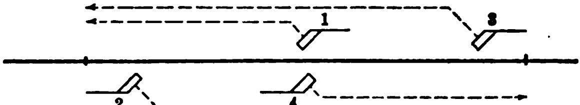


FIG. 2.—Intermediate signals.

Signaling Schemes for Suburban and Interurban Service

The selection of a signaling scheme for a given service calls for a special study of each case. The following general schemes (Figs. 3 to 17, inclusive) for suburban and interurban service were suggested by the 1913 Joint Committee on Block Signals for Electric Railways, A.E.R.E.A., as being usable in the development of such a study.

Single-track Suburban Railway, Headway 5 to 30 Minutes, Speed not Exceeding 20 Miles per Hour. Employing either non-counting or car-counting signals. (Figs. 3 to 6, inclusive; in which *S* indicates Set, *i.e.*, counting into block, *R* indicates Restore, *i.e.*, counting out of block. Dotted lines from a signal contactor indicate control by that contactor. Arrow heads pointing toward signals indicate setting movements; arrow heads pointing toward contactors indicate restoring movements in the direction as indicated by the arrow head.)

Scheme I. (Fig. 3.) East-bound cars take the siding and west-bound cars remain on the main track. An east-bound car from *A* to *B*, by 1, sets *B* to stop, and *A* is changed to register car into *A–B*. Upon reaching siding at *B* the car is counted out of *A–B* at 2. If *C* is in a permissive indication the car may proceed under 3, thereby counting itself into *C–D*. If, however, a west-bound car is in *C–D*, *C* will be at stop and the east-bound car will remain in the siding until the west-bound car has passed *C* which will be restored at 6. For regular movements east-bound cars count into *A–B* and *C–D* at 1 and 3, respectively, and count out at 2 and 4, respectively. West-bound cars count into *D–C* and *B–A* at 5 and 7, respectively, and count out at 6 and 8, respectively. The contactors are shown connected for irregular movements as, for instance, an east-bound car operating 2 counts out of *A–B*, but if for any reason it should back over 2 it would count into *B–A*; but as it again proceeds eastward it will count out again. West-bound car movements are controlled as illustrated for east-bound, except that the west-bound waits, if necessary, on the main track opposite the siding.

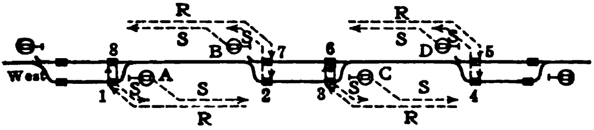


FIG. 3.

Scheme II. (Fig. 4.) Cars in both directions are permitted to pass sidings on the main line; cars in both directions are permitted to run through sidings. An east-bound car having operated 1 sets *B* to stop and *A* to register it into *A–B*. If *C* is in a permissive indication the car passes *B* and counts itself out at 7 and proceeding forward counts itself into *C–D*. If, however, *C* is at stop, indicating a west-bound car in *D–C*, the east-bound car runs into the siding and counts itself out of *A–B* at 2. When *D–C* is re-

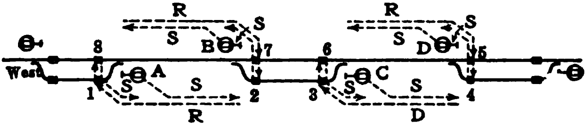


FIG. 4.

stored by west-bound car passing 6, the east-bound car then proceeds into *C–D* by operating 3. The reversal of these movements may take place, that is, a west-bound car reaching the siding may pass it on the main track, or if *B* is at stop the car will enter the siding at the east end and wait there until the east-bound car has cleared *B–A* at 7. East-bound cars count into *A–B* and *C–D* at 1 or 8 and 3 or 6, respectively, and count out of *A–B* and *C–D* at 2 or 7 and 4 or 5, respectively. West-bound cars count into *D–C* and *B–A* at 4 or 5 and 2 or 7, respectively, and count out of *D–C* and *B–A* at 3 or 6 and 1 or 8, respectively.

Scheme III. (Fig. 5.) East-bound cars enter the siding. An east-bound car approaching siding at *B* has signal *B* at stop protecting it. Upon reaching the siding if *C* shows a permissive indication, the car may proceed on the main line and count itself into *C–D* at 4 and count out of *A–B* at 5. If, however, *C* is found at stop, the car will pull into the siding and count itself out of *A–B* at 6. The west-bound car then passing *C* counts itself into *A–B* at 5 and counts out of *D–C* at 4 and proceeds through *B–A*; the east-bound car will then back out of the siding, count itself into *B–A* at 6 and run on to the main line. Proceeding eastward it will count itself into *C–D* at 4 and continuing forward will count itself out of *A–B* at 5. A west-bound car upon reaching the siding and finding *B* at stop will wait on the main line until the east-bound car takes the siding.

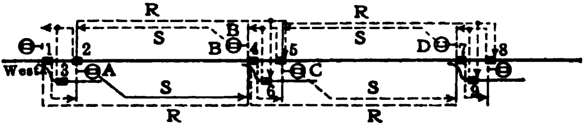


FIG. 5.

Scheme IV. (Fig. 6.) Either east- or west-bound cars take the siding, observing the rule that cars are to head in and back out.

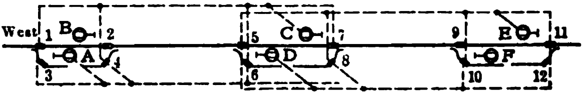


FIG. 6.

An east-bound car in *A–C* has *C* protecting it and upon reaching siding at which *C* is located and finding *D* at permissive, may proceed on the main track and count into *D–E* at 5; continuing forward it will count itself out of *A–C* at 7. If, however, *D* is at stop, the car will head into the siding and count out of *A–C* at 6. The west-bound car then approaching *C* and finding it clear counts into *C–A* at 7 and continuing forward restores *E–D* at 5. The east-bound car in the siding now backs out on to the main line and in passing under 6 counts into *C–A*; then proceeding eastward on the main line counts into *D–E* at 5 and counts out of *C–A* at 7. As the arrangement is symmetrical from the middle of the siding, movements the reverse of the above are controlled in an obvious manner.

Double-track Suburban Railway, Headway 1 to 10 Minutes, Speed not Exceeding 30 Miles per Hour. (Figs. 7 to 11 inclusive.)

Scheme I. (Fig. 7.) Three position semaphore signals with track circuit control. An east-bound car passing 1 sets it to stop, in which position it remains until this car has passed out of *A–B*. Upon passing insulated joints *B*, 3 indicates "stop," 1 indicates "caution." When the train proceeding eastward passes insulated joints at *C*, 1 will go to clear, 3 to caution and 5 to stop. A similar explanation holds for a west-bound train.

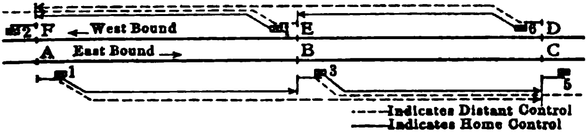


FIG. 7.

Scheme II. (Fig. 8.) Two position signals with track circuit control. An east-bound car passing 1 sets it to stop when it passes insulated joints at *A*. The signal remains in this position until the car passes insulated joints at *D*. As the car passes 3, insulated joint *C*, this signal will also go to stop, and while the car is in *C–D* both 1 and 3 will be at stop. The fact that 1 is controlled beyond 3 to *D* prevents a car obtaining a clear indication at 1 and receiving a stop indication at 3, with the preceding car just beyond this signal. A similar explanation holds for a west-bound car.

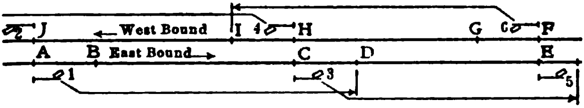


FIG. 8.

Scheme III. (Fig. 9.) Two position signals with track circuit control. An east-bound car passing 1 does not set this signal at stop immediately upon passing it, and does not do so until it has passed over insulated joints at *A*. 1 remains at stop while the car is in *A–B*. In passing out of *A–B* and into *B–C*, 1 goes to clear and 3 goes to stop. A similar explanation holds for a west-bound car.

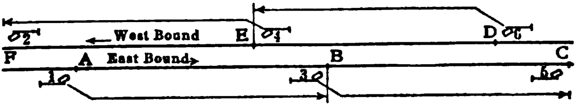


FIG. 9.

Scheme IV. (Fig. 10.) Trolley contactors. Three indications by lights alone, a small pilot light being used in advance of the main signal for an indication that the signal has operated. An east-bound car passing *A*, in case there are no cars between *A* and *C*, changes 1 from neutral to proceed. The fact that the pilot light, which is normally extinguished, lights up, shows the motorman that he has counted into the block and gives him the right to proceed. 1 is at stop while the car is in *A–B*. Upon passing under *B*, 1 is changed from stop to caution and 3 is set to stop, these indications remaining while the car is in *B–C*. Upon passing under *C*, 1 goes to clear or neutral, 3 changing from stop to caution and 5 being set to stop. The fact that the contactors are located immediately at the signals instead of in advance of them, as is customary for single-track operation, makes the pilot light necessary, so that the motorman can be assured that he has counted into the block. West-bound cars will operate in a similar manner.

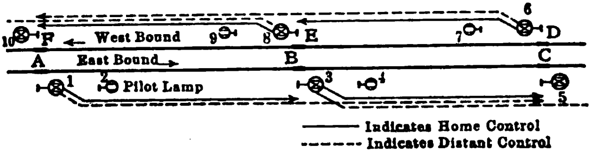


FIG. 10.

Scheme V. (Fig. 11.) Trolley contactors. Light signals giving two indications. An east-bound car approaching *A* does not pass under it unless 1 is at neutral. If this is the case, the car in passing

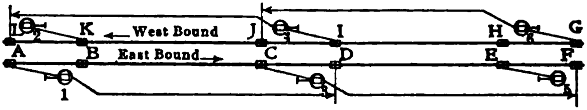


FIG. 11.

under *A* changes the signal from neutral to proceed, the signal remaining at this indication until the car passes under *B*, at which point the proceed indication is extinguished and the stop displayed. The car in proceeding eastward and approaching *C*, if it finds 3 at neutral, proceeds under *C* and if the signal changes from neutral to proceed, proceeds into *C–E*. The car in passing under *D* restores 1 to neutral, changing 3 from proceed to stop. West-bound movements are made in a similar manner.

Single-track Interurban Railway, Headway not Less than 1 Hour, Speed 40 to 60 Miles per Hour. (Figs. 12 and 13.)

Scheme I. (Fig. 12.) Absolute blocking, semaphore signals, only one track circuit from siding to siding, continuous track circuits, following cars blocked from siding to siding, no track circuit preliminaries being used, intermediate signals replacing the preliminaries. Light signals may be used if desired. Cars on siding within clearance limits do not affect signals. An east-bound car passing *A* sets 1, 4 and 6 to stop and protects itself against both following and opposing movements. 3 does not go to stop immediately as the train passes it, due to the fact that the track circuit is not cut opposite the signal. It does go to stop, however, after the train reaches some point as *C* in advance of this signal. This fact is not material, however, as the car is already protected from the rear by 1, but 3 having gone to stop after the car has passed C clears 1 so that the following car may proceed to 3. Proceeding eastward, as the car passes *D*, 4 goes to clear.

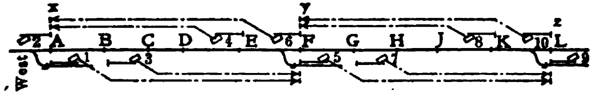


FIG. 12.

West-bound cars are, however, blocked at 6. In passing the insulated joint at *F*, 1 and 3 behind the car change from stop to proceed, allowing a following car to enter the block recently occupied by the first car. 6 will also change to clear, due to the fact that until a following car enters the block at *A* the block is unoccupied. In case there had been a meeting point at siding *Y*, the east-bound car would, on approaching 5, have found it at stop, due to the west-bound car, with which it had to meet, being between *L* and 5, because 5 is controlled to *L*. The purpose of 3 and 4, and 7 and 8 is to protect against the possibility of two opposing cars passing 1 and 6 simultaneously, both in this case being at clear. If this occurred, however, each car would receive the stop indication at 3 and 4 and in this way the advance signals 3 and 4 take the place of the additional track circuit usually used as a preliminary section.

Scheme II. (Fig. 13.) Absolute blocking, semaphore signals, following cars blocked from siding to siding. Track circuit preliminary is used with this arrangement. Light signals may be used

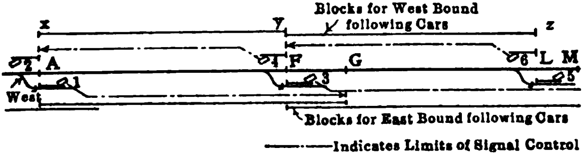

Blocks for West Bound following Cars
X
Y
Z
2
A
4
F
G
6
L
M
1
3
5
West
Blocks for East Bound following Cars
Indicates Limits of Signal Control

FIG. 13.

if desired. Also a light indicator may be used at the beginning of the preliminary to indicate, to a car approaching the siding from side on which the preliminary is located, the indication of the home signal at the siding before it is reached. An east-bound car passing 1 sets it and 4 to stop, thereby obtaining protection for both opposing and following moves. Proceeding eastward if there be a meeting point at siding *Y*, 3 will be at stop if the west-bound car has passed the preliminary section *M*, east of siding *Z*. The east-bound car then proceeds into siding *Y*, which clears 4 so that the west-bound car may proceed without stopping. The east-bound car then backs out of siding *Y* and, providing that 3 is clear, proceeds eastward. 1 is controlled beyond 4 to *G*, this being done so that two cars cannot simultaneously pass 1 and 4, in this way both securing the clear indication. If, with a meeting point at siding *Y*, the west-bound car passes *G* before the east-bound car passes 1, 1 will go to stop and remain so until the west-bound car reaches the clear at siding *Y*. In order to overcome this, an indicator light is sometimes used at *G*, so that the motorman of the train approaching the siding at which he has a meeting point may know before he passes the preliminary section whether or not the opposing train has passed the siding in advance. This scheme can be used with distance signals if desired, continuous track circuits being used.

Single-track Interurban Railway, Headway 15 Minutes, Trains in Several Sections, Speed 40 to 60 Miles per Hour. (Figs. 14 to 16, inclusive.)

Scheme I. (Fig. 14.) Absolute blocking, semaphore signals, following cars blocked practically one-half the distance between sidings, no track circuit preliminary being used, intermediate signals replacing the preliminaries. Light signals may be used if desired. Cars on siding inside clearance limits do not affect the signals. This scheme is somewhat similar to that shown under Scheme I, page 788, except that the intermediate signals have been moved farther into the block and arranged so that following cars can operate more closely than is possible with that arrangement. An east-bound car passing *A* sets 1, 4 and 6 to stop, thereby protecting itself against both following and opposing movements. Proceeding eastward, 3 goes to stop as the car passes *C*, 1 and 4 go to clear as the car passes *D*, thereby permitting a following car to pass 1 in the clear position, the distance between 3 and 4 being braking distance at maximum speed. If there be a meeting point at siding *Y*, the first east-bound car will find 5 at stop, due to tho fact that the west-bound car, that it is meeting, is between *L* and 5, 6 being at stop against the west-bound car. The east-bound car takes siding at *Y* which clears 6 for the west-bound car providing no following east-bound car is between *A* and 6. If a second east-bound car, however, followed the first into *A–F* after the first car passed *D*, 6 will remain at stop until the second east-bound car reaches siding *Y* and gets into clear, when 6 will clear for the west-bound movement. The two cars on siding *Y* now back out and the first proceeds eastward, 5 being clear. The second east-bound car, how-

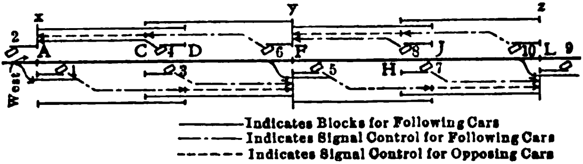

X
Y
Z
2
A
C
4
D
6
F
8
J
10
L
9
1
3
5
H
7
West
Indicates Blocks for Following Cars
Indicates Signal Control for Following Cars
Indicates Signal Control for Opposing Cars

FIG. 14.

ever, waits at 5 (which was put to stop when the first east-bound car passed it) until the first car passes *J*, when 5 will again clear. The second east-bound car may then proceed. 3 and 4, and 7 and 8 serve double purposes; they not only divide the blocks for following movements but take the place of a preliminary track section in the same manner as explained in Scheme I, page 787; *i.e.*, if two opposing cars passed 1 and 6 simultaneously, both receiving the clear indication, they will be stopped by 3 and 4, respectively, in which case one car would have to back up to the nearest siding. This scheme uses but one track circuit from siding to siding, continuous track circuits being used.

Scheme II. (Fig. 15.) Absolute blocking, semaphore signals, continuous track circuits, following cars blocked practically one-half the distance between sidings for following movements and from siding to siding for opposing movements. Light signals or signals

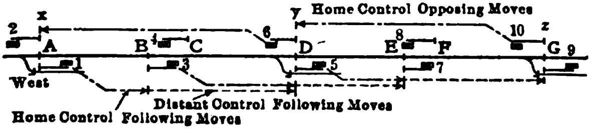

y Home Control Opposing Moves
x
2
A
B
4
C
6
D
8
E
F
10
z
G
9
1
3
5
7
West
Distant Control Following Moves
Home Control Following Moves

FIG. 15.

operating in three positions may be used. Cars on siding inside clearance limits do not affect the signal. An east-bound car passing 1 will set 1, 4 and 6 to stop, thereby protecting itself against both following and opposing moves. Proceeding eastward and passing 3, which will go to stop and 1 changes from stop to caution. On reaching siding *Y*, if a meeting point is to be made at this siding, 5 will be at stop if the west-bound car has passed *G*, and while the east-bound car is on the main line 6 will be at stop and 8 at caution. After the east-bound car gets in the clear at siding *Y*, however, 6 and 8 will go to clear, providing no second east-bound car is between *A* and *D*. After the west-bound car has passed siding *Y* the east-bound car backs out of siding and providing 5 is clear proceeds eastward. With this arrangement both the stop and caution indication are given. The distance from *B* to *C* and from *E* to *F* is braking distance at maximum speed. The overlapping of *A–C* and *B–D* takes the place of a preliminary beyond the siding in the same manner as described in Scheme I.

Scheme III. (Fig. 16.) Continuous track circuits. Cars are allowed to follow one another into an occupied block under a permissive indication. The blocking of opposing cars is absolute. Signals in one direction are normally clear, in the other normally danger. A light indicator is used at the beginning of the preliminary section, also a secondary light is used on the signal to provide the permissive feature. Light signals may be used if desired. An east-bound car passing 1 will set this signal to stop, 4 having already been set to stop at the beginning of the preliminary west of the siding *X*. 1 being normally at danger is changed to clear by an east-bound car entering the preliminary west of siding *X*, providing there is no opposing car between *A* and *C*. Likewise, 3 is cleared by an east-bound car passing *B*, if no opposing car is in *C–E*. After one east-bound car has passed *A* another may follow it into *A–C* providing the permissive light below the semaphore arm at stop lights up, and so on for any number of following cars. The first car approaching siding *Y*, if there be a meeting point at this siding, will find 3 at stop and the light indicator lighted, if the opposing car has passed *E*. If the west-bound car has not yet passed *E*, the east-bound car should wait at the light indicator until it lights up, this indicating that the west-bound car has passed 6 and that the east-bound car may proceed by *B* without blocking the west-bound car a siding away from the meeting point. West-bound cars approaching siding *Y* may proceed at once to the home signal as 1 is controlled only to 4, the preliminary section usually being on but one end of the block. The east-bound car after waiting at the light indicator until it shows that the opposing car has passed 6 then proceeds to siding and gets in the clear, which will allow 4 to clear, provided no other east-bound cars have passed into *A–C* under the permissive indication. After the passing of the west-bound car, the east-bound car in siding *Y* backs out and proceeds past 3 providing it is clear. Distant signals may be used with this scheme in which case the east-bound distant signal would take the place of the light indicator.

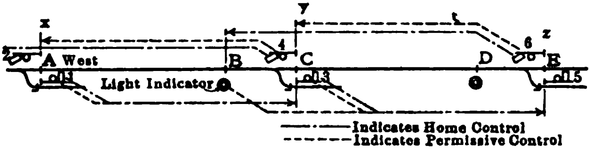

X
Y
Z
A West
B
C
D
E
4
6
1
3
5
Light Indicator
—·— Indicates Home Control
------ Indicates Permissive Control

FIG. 16.

Double-track Interurban Railway, Headway 5 Minutes, Speed 40 to 60 Miles per Hour. (Fig. 17.) Continuous track circuits. Semaphore signals operating in three positions are used, the distance between signals being governed by the headway and speed. The operation is the same in either direction. Light signals may be used if desired. A car passing 1 sets it to stop, proceeding eastward past 3, this signal will go to stop and 1 will change from stop to caution. On passing 5, 3 will go to caution, 5 going to stop and 1 will change from caution to clear. In this arrangement stop and caution signals are displayed behind each car. Cars are

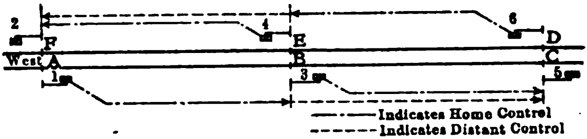


FIG. 17.

able to follow each other as close as the distance between two adjoining signals, the second car in this case running under the caution indication continuously.

Signal Indications and Aspects.

(1) A.E.R.E.A. Standard Use of the three fundamental indications. In all signaling the use of three fundamental indications: (a) Stop; (b) proceed-with-caution; (c) proceed.

(2) A.E.R.E.A. Standard Use of semaphore signals. Where semaphore signals are used they shall be so arranged as to indicate (indicating in) three positions, in the upper left-hand quadrant.

(3) A.E.R.E.A. Standard. Aspects in three-position signaling (see Fig. 18).

(4) A.E.R.E.A. Miscellaneous Methods and Practices. Aspects in two-position signaling (see Fig. 19).

Spectacle. Fig. 20 shows the design of spectacle for left-hand upper quadrant 90 deg. semaphore having 6 in. openings and 6½ in. lenses for 3-position semaphore signals and for use with 3 ft. 6 in. pointed blade, adopted as standard by the A.E.R.E.A., 1914.

Clearances for Block Signal. Fig. 21 shows the clearance diagram for block signals recommended by the Committee on Block Signals A.E.R.E.A., 1914, for adoption as standard.

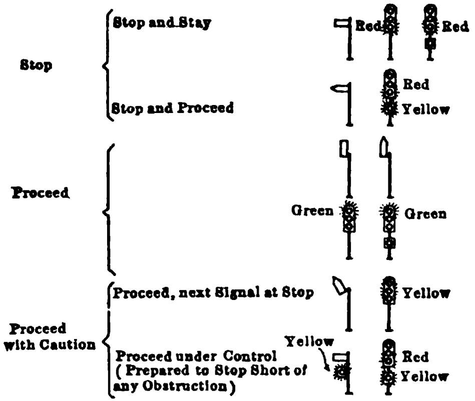


FIG. 18.—Aspects in three-position signaling. A.E.R.E.A. standard.

Discernibleness of Light Signal in Sunlight. The following results of tests by Mr. John Leisenring are from a discussion by him, A.E.R.E.A., 1912:

A standard semaphore signal indicating in the upper left-hand quadrant was placed on a long tangent running almost directly east and west. A light signal with 5-in. lenses, two 24-watt tungsten lamps behind each lens, with a 30-in. straight hood and a collar of about 10 in. for forming a background, was located near the semaphore, the green lens being above the red. The background

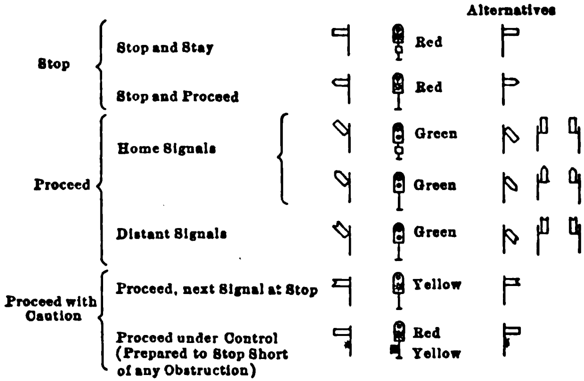


Fig. 19.—Aspects in two-position signalling. A.E.R.E.A., proposed practice.

was of the ordinary type encountered on interurban railways, trees being the main formation of the one in question. The poles on the side of the track on which the signals were placed are 8 ft. from the center line of the track. Construction is mast-arm, and the trolley wire is 18 ft. 6 in. from the top of the rail. At 7:05 a.m., Oct. 5, a bright clear morning with a slight haze near the ground,

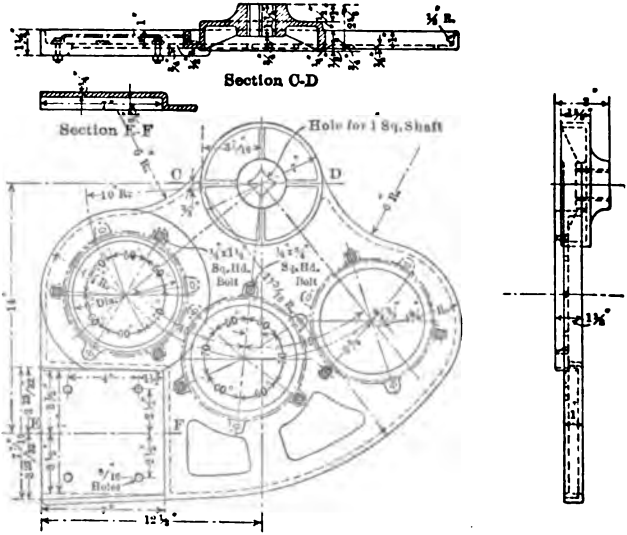


Fig. 20.—Spectacle design for three-position semaphore. A.E.R.E.A.

looking directly into the sun, which was slightly off to the right-hand side with the side of the pole toward the observer in the shadow, the limit of sight of the green light in the signal above described was 2050 ft., and the limit of sight of the red was 1850 ft. The whole front of the signal was entirely in the shadow. The semaphore signal, under the same conditions of light as stated above, could be seen in the "stop" position, horizontal, distinctly 1500 ft.; in the 60 deg. position, which is "proceed" on the road in question, it was clearly discernible 840 ft.; in the 90 deg. vertical position, which would be the "proceed" indication in three-position signaling, it was clearly discernible 750 ft. At 10.30 a.m. with the sun

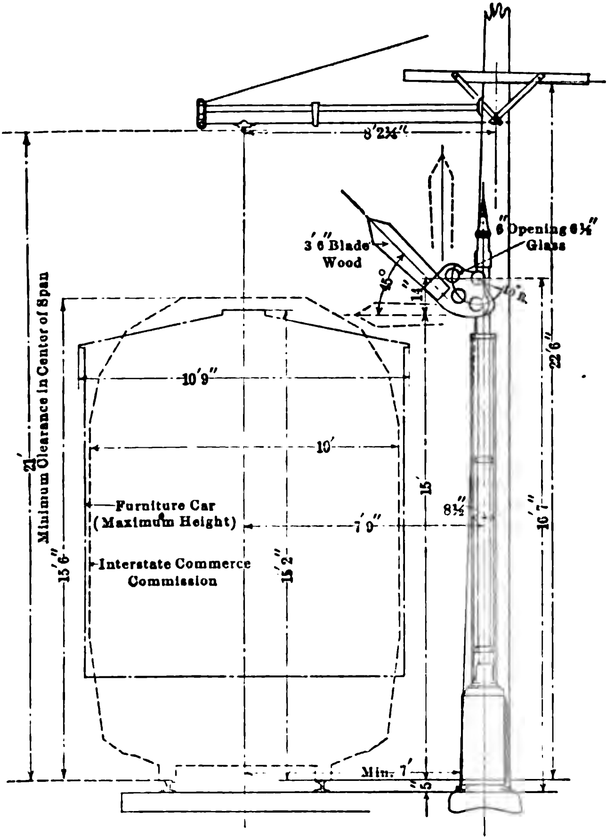


FIG. 21.—Clearance diagram for block signals. A.E.R.E.A.

high and the short shadows almost at right angles to the track, the side of poles toward the observer being still in the shadow, the limit of sight of the green light in the light signal was 2000 ft.; the limit of sight of the red indication was 1700 ft. The semaphore signal was clearly discernible in the horizontal position, under same light conditions as above, about 2500 ft.; in the 60 deg. "proceed" position about 1500 ft., and in the 90 deg. "proceed" position about 1450 ft. At 3:30 p.m. with the sun shining into signal at slight angle, both lenses being in the shadow, the sides of the poles toward the observer being in the sunlight, the limit of sight of the green indication was 1650 ft., and the limit of sight of the red indication was 1122 ft. The direct sun's rays were on the front of the signal, just to the edge of the red, or lower, lens. The semaphore signal under similar conditions in the horizontal position could be seen for 3645 ft.; in the 60 deg. position for 2500 ft., and in the 90 deg. position for about 2000 ft. At 5 p.m., when the sun was beginning to weaken and when its rays were directly on the lenses of the light signal, the green indication was discernible for 3000 ft. and the red indication for 1350 ft. The semaphore signal was practically the same as stated in the last previous observation.

Size of Lens. The Joint Committee on Block Signals for Elec. Rys., A.E.R.E.A., 1914, recommended as follows for good practice:

High-speed Interurban Service. A lens of not less than 8⅜ in. diameter should be used on all light signals operated by continuous track circuits.

Moderate Speed Service. A lens of not less than 5⅜ in. diameter should be used where light signals are operated by trolley contact or other end set devices.

Manually Operated Lamp Signal. (Fig. 22.)[*] This is one of the simplest types of signals and is in very common use. The lamps are grouped to operate on trolley potential and but one additional signal wire extending through the block is used. A member of the crew of a train about to enter a block throws a switch, thereby displaying a light at the distant end of that block with a caution signal at the entering end. When the train reaches the end of the block, a member of the crew throws a switch at that

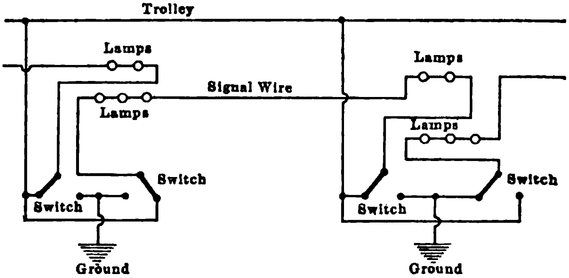


FIG. 22.—Manually operated lamp signal.

leaving end, thereby removing the signals set by him at both ends of that block. If, however, two trains running in the same direction occupy one block at the same time, the signal should not be removed until the last train leaves the block. In some cases, one lamp only is used in the signal box at each end of the circuit, while the remaining lamps of the series are installed at appropriate places along the section as an assurance to the motorman that his protection remains as set.

The signal should be arranged to prevent unauthorized manipulation. This is commonly done by padlocking the operating handles. The following scheme developed by the Rhode Island Co. for the protection of hand operated signals also insures the removal of the reverse handle from the car while the signal is being set: Snap switches are used instead of knife switches. A round piece of metal having a square hole in one end is substituted for the ordinary rubber button on the snap switch. The switch is mounted so that this square hole is slightly above an opening in the bottom of the signal box. The motorman's reverse handle, having one end squared for the purpose, is used as a key to turn the switch.

Manual Block System. The manual block system is one in which trains are controlled by signals operated manually, upon information received by telegraph, telephone or other means of communication. It consists of a series of block sections with a block control station at each end of each section, at which there are placed signals to be used by the operator to control the trains entering and using said block. In the operation of this system, information concerning the condition of a given block is obtained by communication between the operators at the ends of said block, and trains are instructed as to movement by means of the signals. The safety of operation under the manual block system depends upon the accuracy with which orders are received and transmitted, there being no check, either electrical or mechanical, to prevent the display of a wrong signal.

Controlled Manual Block System. The controlled manual block system is the same as the manual block system just described except that the signals at the ends of each block are electrically interconnected in such manner that cooperation of the signalmen at both ends of the block is required to display a clear signal. It is a great improvement over the manual block signal, but still does not prevent two operators from making simultaneous error. This is overcome by the continuous track circuit, so arranged that a train having entered a block will automatically put the proper signals to stop and hold them there until the train is entirely out of the section, regardless of any attempt on the part of the operators to clear them. Its use on many electric lines is prohibited on account of the large expense involved in maintaining operators at such frequent intervals. The cost of the electric apparatus for "controlled manual" has been looked upon by most roads as unwarranted. Only roads with heavy earnings are using it.

Staff or Token System. The staff or token system is another form of controlled manual block system which has been applied only to single track lines. In its operation no train is allowed to occupy a block section without the possession of a tangible object, such as a staff, ball or tablet. These tokens are obtained from instruments located at the opposite ends of each block which are so interconnected, electrically, that but one token can be removed at a time; and until this one has been replaced in one instrument or the other, no additional token can be withdrawn from either. Therefore, it is evident that there can be but one train in a section at a time except where permissive blocking is used, in which case the tokens are made in pieces, each train taking part of a token, the last train taking all that remains. When, therefore, this divided token is put together and deposited in the other instrument, another token can be withdrawn from either instrument. The strong feature claimed for this form of controlled manual blocking is that it requires the train crew to take part in the operation and gives the engineman tangible evidence of his right to the block. Its drawbacks are that thus far it has required the train to stop to deposit and withdraw the tokens or else requires operators at each passing point to receive and deliver them.

Automatic Block System. The automatic block system is a system in which the signals govern the entrance to each block and are automatically controlled by the trains as they proceed, in such a manner that head-on and rear-end protection is afforded. A number of forms of the automatic block systems are being used' their essential differences appearing in the manner in which the control of the signals by the train is effected. These different forms of automatic systems include the following methods of control: (1) Trolley or auxiliary rail contacts, which are operated by passage of trolley or third-rail shoe and thus operate the signal circuits when a train passes; (2) continuous track circuit, based on a fundamental principle of a train controlling, at all times, the signals governing the specific portion of the track occupied, and utilizing the track rails as a signal circuit; (3) short track circuit, which utilizes short insulated sections of the track at the ends of the block for setting and restoring signals.

Trolley Operated Signals. Trolley operated signals are generally operated by electrical contact through the current collector of the car or by electrical contact through a switch which is opened or closed mechanically by the current collector in passing.

Contact Type Trolley Operated Signal. Fig. 23 shows the relation of the essential parts of a typical trolley contact signal (the Nachod). The mechanism of the signal itself may be divided into three parts: (1) The indicating, consisting of the lamps, color lenses and opaque color disks; (2) the intermediate, represented by the relay, which converts the impulses of current caused by the passage of the car into signal indications; (3) the actuating, consisting of the overhead trolley contact switches, which by the passage of the car determine the setting and the clearing of the signals. The trolley switch consists of a light angle-iron frame supporting at its ends through insulating blocks, two flexible inclined contact strips, the trolley wire being withdrawn during the length of the contact strips, which are formed to receive the wheel without shock. One strip is connected to trolley, the other to ground through the relay. The wheel, being a metallic conductor, bridges them and sets the signal whether the car is taking power or not at the instant of passing the switch. One signal wire in addition to the trolley wire connects the apparatus at the ends of the block. Fig. 23 shows the parts in position for no train in the block, in which case each end of the signal wire is grounded through a red lamp *R*. With no current in the coils, the armatures drop. The first entering train sends proper current through magnet *A* in the relay at the entering end, operating a two-way revolving switch, which transfers that end of the signal wire to trolley through a white light *W* and a magnet *D*. This light and the red one at the other end now burn in series through the signal wire. Successive following trains turn the revolving switch so that the contacts overlap further, but make no change in the electrical circuit. Each leaving train energizes magnet *C* to break temporarily the signal circuit at 9–1, permitting magnet *D* in the first relay to drop its armature and revolve the switch in the reverse direction. When the same number of impulses has been made on magnet *C* as on *A*, that is, when all the trains that have entered the block have left it, the signals are cleared and the connections are as shown. The color disks are brought to an indicating position by magnet *D* and one in shunt with *R*, not shown. A no-voltage magnet, not shown, is interlocked with magnet *D* to prevent a motion of the armature of the latter should the power fail with trains on the block. This is a signal of the absolute, permissive type. To illustrate the permissive feature, suppose a train has entered the block and set the signals, and before it leaves, a following train arrives at the end of the block showing white. The motorman will understand by this that there is at least one train ahead going in the same direction. As his train runs under the contact he notices the flash of the white light that his train causes. This is an indication that his train is counted in or registered in the signal relay; and so on for a number of trains following each other, each receiving its signal that there are other trains ahead of it and that it has counted in. When the first train arrives at the end of the block, in running under the contact switch, it causes a blinking of the light, but the signals are set as before. They so remain until the last train clears them, leaving

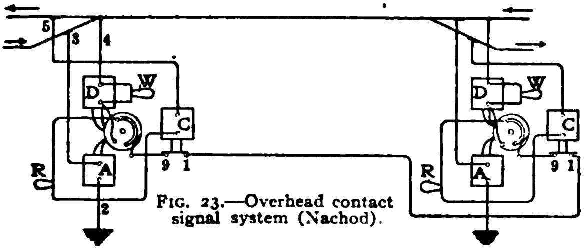


FIG. 23.—Overhead contact signal system (Nachod).

block ready for trains in either direction. If a train should enter the block from one end and back out by the other track at the same end, using the single track merely as a Y or cross-over, the signals will be cleared when the train leaves the block. This makes a very flexible operation, as in the complicated case where a number of trains enter the block from one end, and are continuously entering and leaving, some leaving by one end and some by the other, but the signals protect all the trains in the block and are cleared only when they all leave it. The signal may also be operated as an absolute block system by leaving the hand-clearing switch open, which is equivalent to opening the line wire. For instance, the motorman of a work train, entering the block closes the block at both ends by leaving the hand-clearing switch open. Then no permissive signals may be obtained from either end. To leave the signals for normal operation again, he must close the switch when leaving the block. In case of failure of line voltage, the signals reappear on its resumption with the same indications.

Fig. 24 shows the circuits of another typical trolley contact signal (the United States).

The right-hand front magnet is the setting magnet which rotates the registering wheel one step for each energization. The left-hand front magnet is the restoring magnet which at each energization rotates the registering wheel one step in the direction opposite to the above. The front or main contact bar is in its right-hand position when the block is clear, but is thrown to its left-hand position when the first car is registered into the block on the registering wheel and remains in the left-hand position until the last car is registered out. The middle contact bar or alternating switch is operated by a star cam on the registering wheel so that it stands in its right-hand position when each odd car is registered in, and in its left-hand position when each even car is registered in. When it is in its right-hand position, it causes the right-hand green and white semaphore to be displayed, and when it is in its left-hand position it causes the left-hand green and white semaphore to be displayed so that the proceed indication will be given only when the registering wheel operates. The rear contact bar, normally in its right-hand position, is momentarily thrown to its left-hand position when the rear right-hand magnet is energized, but as soon as the latter is de-energized falls to its normal position. This magnet is energized by the restoring trolley contactor.

The trolley wheel of a car entering an unoccupied block from the left strikes the setting contactor, thus completing a circuit from trolley wire, through fuse 4, through setting (right-hand lower) magnet, resistance and fuse G to ground. This moves the registering wheel one notch and moves the main (front) contact bar to the left-hand position. As soon as the trolley passes beyond the contactor the circuit previously made is opened and the armature of the setting magnet falls back by gravity into its normal position. A circuit is then completed from the trolley wire at the right-hand end of the block, through the wire indicated by the heavy line, fuse 1 in the right-hand signal, resistance, red lamp, pick up magnet, front left-hand magnet, the two right-hand contacts and main contact bar, the contacts and the rear contact bar, rear left-hand locking magnet, fuse 3, signal circuit line wire, fuse 3 in the left-hand signal, rear left-hand locking magnet in the left-hand signal, rear contact bar, upper contacts and main contact bar, around through contacts and middle contact bar, right-hand permissive semaphore magnet, green light, pick-up magnet, thence to ground. If a second car passes over the contactor, setting magnet will be

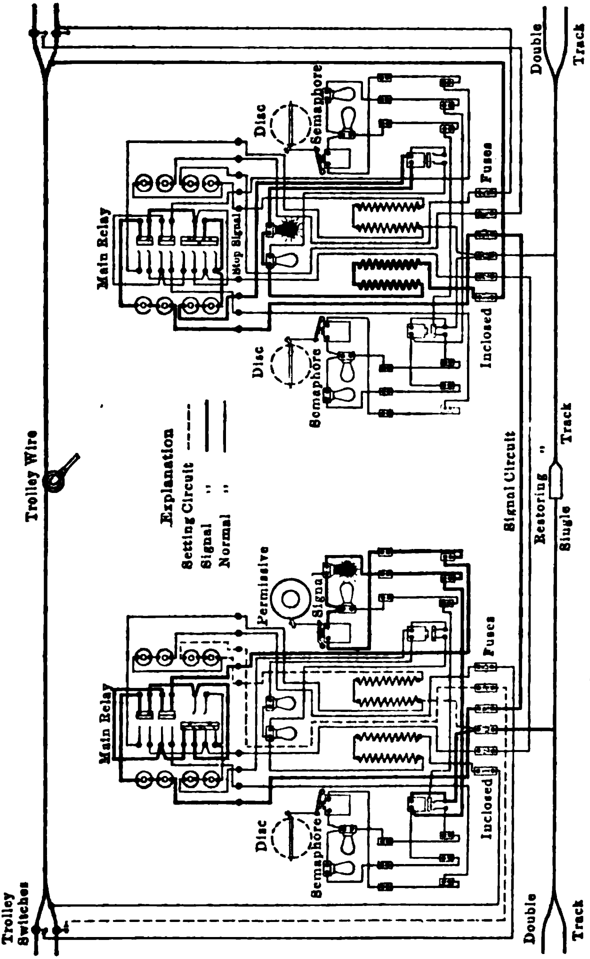


FIG. 24.—Overhead contact signal system (U.S.).

energized in the manner above outlined for the first car and the registering wheel will be rotated one more notch, the middle contact bar or alternating switch will be thrown to the left-hand position. The circuit through the signal at the right-hand end of the block will then be completed as above outlined, but the circuit through the left-hand signal will be completed as follows: From fuse 3, through rear left-hand locking magnet, rear contact bar, upper left-hand contacts, main contact bar, left-hand contacts and middle contact bar, left-hand semaphore magnet, left-hand green light, pick up magnet, thence to ground. This will cause the opposite green semaphore disk to show. When the trolley wheel passes the restoring contactor at the right-hand end of the block, a circuit is completed through fuse 5, rear right-hand magnet, resistance, thence to ground. This moves the rear contact bar to its left-hand position, opening the signal circuit previously described and completing a circuit across the left-hand pair of contacts. This action completes the restoring circuit as follows: From the trolley wire at the left-hand end of the block, through fuse 1, resistance, red lamp, pick-up magnet, restoring magnet, lower left-hand contacts and main contact bar, fuse 2, restoring circuit line wire, fuse 2 in the right-hand signal, left-hand pair of contacts and rear contact bar, thence to ground. This energizes the restoring magnet in the left-hand signal and rotates the registering wheel one step in the direction opposite to that in which it was rotated by the setting magnet. As the trolley leaves the restoring contactor the circuit just described will be opened, rear right-hand magnet in the right-hand signal will be de-energized and the rear contact bar will fall back to the right-hand pair of contacts. This places the signal circuit in its normal condition. When the last car is counted out of the block, the main contact bar in the left-hand signal is thrown to its right-hand position. Both signals are then neutral. If a car enters the block from the right-hand end, the circuits will be completed in the same manner except they will be fed in the opposite direction, that is, from the left-hand end of the block.

Single-rail Track Circuit Alternating-current Signal System. Fig. 25 shows the relation of the essential parts of a track circuit alternating-current signal system in which one rail (the "block rail") is insulated in sections and is used to carry only current of the signal system. The other rail is used to conduct the train propulsion direct current and the current of the signal system. Alternating current whose potential is reduced from that of the signal mains by transformers at the block is used to operate the signals. A non-inductive resistance is placed in series with the secondary of the transformer which supplies the current for the track signal circuit. A non-inductive resistance is likewise placed in series with the signal relay and an inductance is shunted across the signal relay. The purposes of these resistances and the inductance are to reduce to a negligible value the direct current which, due to the drop in potential of the train propulsion current in the block, flows in the relay and the track transformer, also to limit the flow of alternating current through the track transformer when the rails are bridged by wheels and axles of a train in the block. The magnetic circuits of inductance and transformer each include an air gap to diminish the magnetic effect of the small direct current which passes through their windings. Wheels and axles of a train in the block shunt the signal current, thus causing the relay to release its armature and set the signals.

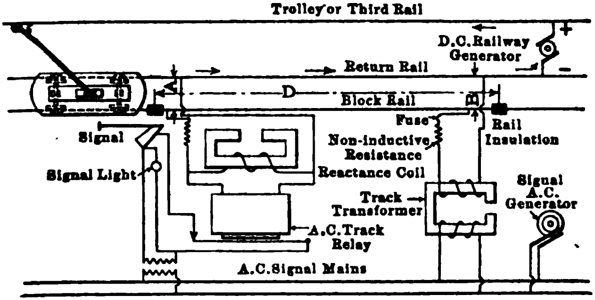


FIG. 25.—Single-rail alternating current block signal.

Double-rail Track Circuit Alternating-current Signal System. Fig. 26 shows the relation of the essential parts of a track circuit alternating-current signal system in which both rails are used in common by the signal alternating current and the train propulsion direct current. This common use is made possible by the inductive bonds which, while offering little resistance to the train propulsion current, maintain a considerable alternating-current potential difference between the rails when there is no train in the block suppiied by the track transformer. While this considerable alternating-current potential difference continues the armature of the relay holds the signals at the normal indication, but when, as by the bridging action of the wheels and axles of a train in the block, this alternating-current potential is greatly reduced, the armature of the relay is released and the signals are set. The inductive bond consists of a single winding of heavy conductor on a

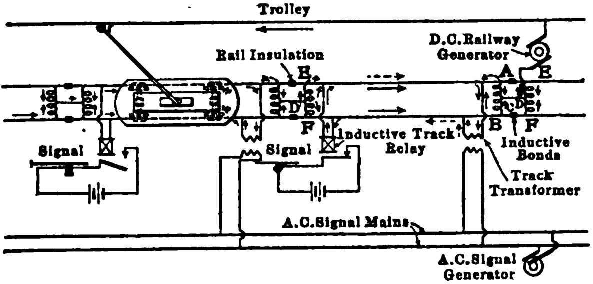


FIG. 26.—Double rail alternating current block signal.

laminated iron core and having a tap brought out at its middle point. (The magnetic circuit for use with direct current for propulsion includes an air gap.) The bond is connected across the rails at one end of an insulated section of track and the middle tap is connected to the middle tap of a similar bond connected across the rails at the adjacent end of the adjoining insulated track section. To limit the flow of current supplied by it, the track transformer is provided with an adjustable leakage path between its primary and secondary windings.

This system is also used where alternating current is used for train propulsion. For this service the frequency of the current in the signal circuit is greater than that of the train propulsion current. The impedance bonds have no air gaps. They offer little impedance to the train propulsion current, but they offer sufficient impedance to the signal circuit current. The relay is constructed to operate only with current of the higher frequency.

Short Track Circuit Signal System. In the short track circuit system only short insulated sections of track at the ends of the block are used in the signal operation. The following outline is based on the Kinsman system. Special provision for signal operation is made between adjacent rails of but one side of the electric railway track, thus the other rail is left continuous as if it were to serve only the needs of train propulsion. The track circuit includes two adjacent insulated sections, each two rail-lengths long. The sections are insulated by three insulated joints. The section farther from the center of the block controls the setting of the signals, while the second section controls the release of the signals. The return circuit of the train propulsion current is carried around these insulated sections by an auxiliary conductor, either rail or cable. The relays are operated by current from a primary battery. When the block is "clear" the normal position of the signal arm is vertical. The train in entering the block first passes over the setting section and operates the setting relay. This cuts out a release relay and makes both insulated sections a setting section. If a train is leaving a block it first passes over the release section, cutting the setting relay out of circuit and making both sections a release section. A step-by-step controller at each signal registers the movement of the trains into and out of the block and controls the circuit operating the signal. The controller switch is not thrown back to its normal position until the last train leaves the block. The position of the signals is controlled by the position of the controller switch. When the block is unoccupied this switch is at normal position and the signals at both ends are in vertical position. As a train enters a block the setting relay operates the controller at the entering end and the controller switches open. This breaks the circuit, de-energizing the signal at the distant end of the block, allowing it to fall by gravity to the horizontal or "stop" position. As a signal assumes the "stop" position it opens the circuit. When an entering train leaves the insulated section, the signal at the entering end is de-energized and falls by gravity to the 45-deg. or "caution" position and is held in this position by a slot magnet which is operated by the switch on the controller.

As each succeeding train enters the block it passes onto the insulated section and the signal moves from the 45-deg. position to the vertical position; then after the train has passed over the insulated section the signal falls back to the 45-deg. position, and the signal at opposite end of block goes to horizontal position. As each train passes out of the block the release relay operates and in turn actuates the controller at the entering end of the block one step back toward its normal position. As the last train passes out the controller switch is operated, which completes the circuit through the signal at both ends of the block, causing both to operate to the vertical position, which indicates that all trains are clear of the block.

Insulating Joints. Where, as at the end of a block, it is necessary to insulate adjacent rail ends from each other, a piece of insulating fiber is placed between the rail ends, insulating bushings are placed around the bolts and insulating fiber is clamped between the rail and the joint plates, the latter having been planed down or specially made for the purpose.

Effect of Zinc-treated Ties on Two-rail Track Circuits. The following is the consensus of opinion obtained in letter replies. It was given by the Committee on Signals and Interlocking, 1913, A.R.E.A., and accepted as information by that association: (1) Track circuits a mile in length are rendered inoperative by the extensive use of zinc-treated ties. (2) Track circuits 2000 ft. in length may be operated successfully, even with 50 per cent. or more of ties so treated. (3) 10 per cent. to 15 per cent. renewals per year will not materially affect such length circuits. (4) Where renewals are made of fifteen or twenty adjacent ties, the leakage is much greater than where they are made singly at uniform distances, *i.e.*, with 15 per cent. renewals (every sixth or seventh tie). (5) While the surface salts are present, more leakage occurs during wet weather than with untreated ties, as these wet salts form a better conductor than ordinary wet wood. (6) In dry hot weather, the salts are drawn to the surface and constitute a more or less perfect conductor. (7) After a period varying from 3 months to a year, these salts disappear and subsequently no interference is noticeable.

Dispatchers' Signal Systems

There are many signal systems in which provision is made whereby a dispatcher may set signals at desired points along the track. Telephone communication between train crew and dispatcher is also generally provided for. The main point of difference between dispatchers' signal systems which set fixed signals is the method whereby the desired fixed signal is selected.

Impulse Systems. In the Blake signal system several signals are connected to the same circuit and each signal contains a pendulum of a length differing from the lengths of all other pendulums in the signals on that circuit. In the dispatcher's office there is a pendulum of the same length as each of the pendulums in the signals. When the dispatcher sets one of his pendulums vibrating it opens and closes an electric circuit, thus sending impulses of current out on the signal circuit. These impulses of current pass through electromagnets in the signals and, in a few seconds, the pendulum of the length of the one started by the dispatcher is made to vibrate by the electromagnet to such an extent that it mechanically trips the release which sets the signal. As the signal sets it closes a sounder circuit to the dispatcher's office, thus giving indication that the signal has been set. There are several signal systems in which a spring or weight-driven selector in the dispatcher's office sends out impulses which will operate a desired signal. The selector signals are generally reset manually at the signal or by cooperation of the dispatcher and someone at the signal.

Simmen Signal System. The Simmen signal system provides a means whereby a signal may be set on a train by the dispatcher and a continuous record showing the location of all trains and the speeds at which they are running through the blocks is drawn in the dispatcher's office. The system operates independently of the train propulsion current supply. The circuits of this system divide into two main parts; the main control circuit (Fig. 27) and the car circuit (Fig. 28). Three sections of third rail (each about 75 ft. long) at the sidings are connected by line wire to relays, dispatcher's control switches and a battery in the dispatcher's office. The return is over the track rails. The car equipment consists essentially of a third-rail shoe, local battery, relay and two signal lamps (one red and one green). The short lengths of contact rail are located one opposite the switch and two others, 2000 ft. distant in each direction. The rail at the siding is called the home rail and the other two are called distant rails. By means of the two rails located 2000 ft. from the siding it is possible to inform the crew of its signal, sufficiently far in advance to permit the stop to be made before the siding is reached. That is to say, if two trains are approaching a siding where they are to meet, they will receive red signals when 4000 ft. apart and each train will yet have 2000 ft. distance remaining in which to come under control to make the siding stop. When a car passes, the

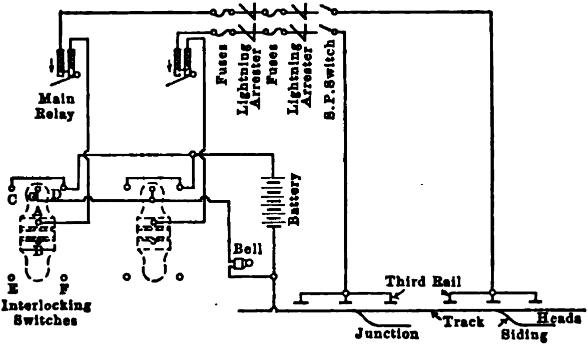


FIG. 27.—Main control circuits, Simmen signal system.

contact shoe attached to the side of the truck touches the third rail. The circuit is then completed through a relay on the car and through the running gear of the car to the rail. Thus the car relay is put in series with the relay and the control switch at the dispatcher's office. If a contact rail is energized (by the closing of the dispatcher's control switch) a "clear" signal will be given on a train passing the contact rail. A "clear" signal received in entering a new block will continue to show "clear" throughout the block, and a "danger" signal once displayed will continue at "danger" until it is automatically cleared when a train is passing an energized third rail. The third rail has inclined approaches at each end. When the contact shoe (Fig. 28) approaches the third rail, the shoe is raised and arm *R* of the contact shoe separates from front stop *S*. If the third rail is energized a circuit is established through the dispatcher's office. With this circuit energized the relay will be energized and its armature will close the circuit through a green or "clear" signal lamp, as well as another circuit to front stop *S*. As soon as the shoe leaves a third rail a spring forces contact arm *R* against front stop *S*, thus closing a local holding circuit. In this manner the "clear" signal is continued throughout the entire block entered. When a car passes a de-energized rail a "danger" signal is displayed and held until an energized third rail is passed. The dispatcher's switches are interlocked to prevent the dispatcher giving a "clear" signal to a train at one end of a block before a "danger" signal is set against an opposing train at the other end of the block. A record of the movement of trains is made on a train sheet driven by clockwork. Elapsed time is measured on the sheet in the direction of motion of the sheet and train location (by blocks) is given perpendicular to this direction. The record is made by needles operated by electromagnets controlled by the main relays in the dispatcher's control switch circuits. There are two needles for each block, one needle records the movement of a train running in one direction through a block and the other needle records the movement of a train running in the other direction through that block. The record is given by a slit cut in the paper by a needle which is made to continue cutting

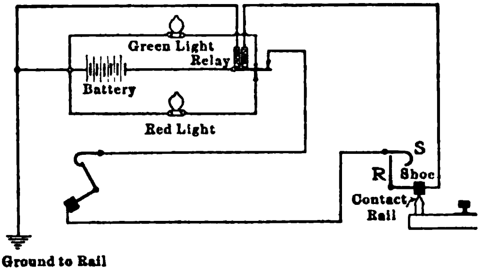


FIG. 28.—Car circuit, Simmen signal system.

the slit throughout the time a train bound in the direction for which that needle records is in the block represented by that needle.

Audible Signal. By this device (Federal Signal Co.) an audible signal sufficiently loud to attract the attention of all persons on a passing train is given. If a train without the brakes applied passes a caution signal, a relay in a track circuit is de-energized. This causes four torpedoes placed at the caution signal to be successively exploded at half-second intervals. Arrangement is made whereby the operation of the audible signal may be prevented from the train if the brakes are applied. This is done by a circuit made through a short contact rail placed beside the running rail.

Signal Maintenance. The following regarding the maintenance of signals, from the Electric Railway Journal, 1914, is an outline of methods in use on the Boston Elevated Railway System, and is an example of good practice. There are about 27 miles of main-line elevated, subway and tunnel track on which about 250 electro-pneumatic signals operate. Some of these are operated by alternating current using double-rail return, the local transformers are supplied from 550 volt mains and the maximum supply to the track circuits is 10 volts. The rest are operated by direct current using single-rail return, the potential of the direct-current supply mains is 110 volts, the potential across the track relays is 15 to 20 volts.

Organization of Signal Maintenance. The maintenance of signals and interlocking and all new construction in connection with either is handled by the company's department of maintenance of way, headed by a chief engineer responsible to the chief of maintenance. Reporting to the former through the superintendent of rapid transit lines is a roadmaster of rapid transit lines, and to the last-named official the head of the signal department reports, with the title of inspector of signals. The inspector of signals is assisted in executive duties by a general foreman of signals, under whom are a foreman of interlocking construction, a foreman of electrical construction, ten signal maintainers, fourteen interlocking maintainers, and a Cambridge subway foreman, under whom are seven men, four being assigned to interlocking and three to signals. Under the foreman of interlocking construction are five constructors and helpers, and under the foreman of electrical construction are also five constructors and helpers. These are two classes of interlocking maintainers, the first class being responsible for both electrical and mechanical interlocking apparatus, and working from 5:30 a.m. to 3 p.m., the second class having no responsibilities in relation to electric interlocking maintenance, but otherwise having the duties of the first class, their working hours being from 3 p.m. to 12:30 a.m. Train service on the rapid transit lines extends roughly from 5:30 to 12:30 a.m. daily. There are also two office foremen who report to the general foreman or the inspector of signals, and who have general charge of all signals and interlocking forces in the absence of both. Maintainers are promoted from construction crews, the senior construction man being utilized as a spare maintainer. He thus has experience in the work prior to becoming full-fledged maintainer. Before attaining this rank the candidate is required to pass an oral and written examination given by the inspector of signals, the written portion dealing mainly with the making and interpretation of signal or interlocking wiring diagrams. The track layout requires the use of eleven interlocking towers, which are in general operated in three daily tricks, as follows: First trick, 12 midnight to 9 a.m.; second trick, 9 a.m. to 6 p.m.; third trick, 3 p.m. to 12 midnight. An overlap is thus provided to care for the afternoon rush-hour conditions. Monthly shifts in tricks are made in regular rotation by signal maintainers. Men on the first trick work in connection with night construction and repair crews are required to understand both electrical and mechanical apparatus. Towermen are directly responsible to the train dispatcher.

Duties of Signal Maintainers. Signal maintainers on the elevated lines and in the Washington Street tunnel work in three daily shifts, viz., 12 midnight to 9 a.m., 9 a.m. to 6 p.m., and 3 p.m. to 12 midnight. Those in the Cambridge subway work from 12 midnight to 9 a.m., from 6 a.m. to 3 p.m. and from 3 p.m. to midnight. The following outline of the distribution of maintenance work on signal equipment in the Cambridge subway illustrates the character of the duties required:

First trick, midnight to 9 a.m.: Inspect all lamps in subway inverts, Eliot Square shop and yard, with necessary replacements. Look after cleaning of all electric light switchboards (sixty-three in number). See that automatic throw-over switches supplying emergency subway lighting current are working properly. Inspect pumps at five pump chambers between Harvard Square and Kendall Square, inclusive. Test cross-over track switches at Kendall and Quincy Squares. Answer emergency calls for light or signal trouble.

Second trick, 6 a.m. to 3 p.m.: Inspect and keep oiled all signal apparatus between Harvard Square and Park Street, covering twenty-four straight electric signals, three electropneumatics on bridge and twenty-seven automatic stops. Inspect pumps in chambers daily and answer emergency calls.

Third trick, 3 p.m. to midnight: Inspect daily and keep cleaned and oiled all pumping apparatus. Inspect and clean ejectors at Harvard, Central and Kendall Squares. Answer light and signal emergency calls. All maintainers keep tower *P*, at Harvard Square, informed as to whereabouts.

Light parts are renewed by maintainers. In renewing resistance tubes, improving contacts, etc., the signal circuit within the case is killed by pulling an inclosed fuse. In general, relay adjustments are made at the office of the inspector of signals by an office foreman, who specializes in this delicate work. In the Cambridge subway a maintainer often receives from fifteen to twenty calls daily to replace burned-out lamps, fuses or other light repairs. The inspection of motor-generator sets in towers which furnish current at 110 volts to the signal mains is handled by signal maintainers, storage batteries being kept in condition by interlocking maintainers.

Signal Maintenance Records and Reports. Each signal department employee is provided with a 4-in. by 8-in. pocketbook blueprints containing the standard symbols of the Railway Signal Association, lists of standard terminal strips, wiring diagrams of all signal, track and supply circuits of typical arrangement on the system, wiring of detector and interlocking machines, surface car signals and track switches, track layouts at important junctions, car clearance diagrams, speed tables, heater wiring, telephone circuits and platform clearances, with an explanation of pneumatic valve operation and other data bearing directly on the work of the department. Reports of signal troubles are transmitted to the train dispatcher by telephone or telegraph and are at once turned over to the signal maintainers and then to the signal inspector's office. Each maintainer upon completing a repair job or upon adjusting any operating trouble reports to the office on a 4-in. by 6-in. slip recording the nature of the trouble, the time required to attend to it, etc., retaining a yellow carbon copy for reference. From the reports of maintainers a 3-in. by 5-in. day card is made up, giving the signal number and the cause of trouble reported, and from the day cards a monthly report to the roadmaster is compiled, showing in summary form the date of occurrence of each trouble, the kind of trouble experienced and an analysis of the month's operations.

Crossing Protection. Automatic highway crossing protection may be afforded by a gate, an audible or a visible signal, or by a combination of these, to warn highway traffic. Which should be used at a given crossing depends upon the traffic conditions on both the railway and the highway, also upon the particular surroundings of the situation. The audible signal is given by either a gong having a frequency of about 200 strokes per minute or by a horn. The visible signal is given in the daytime by the gate itself which is painted so that it is conspicuous against its background and at night by electric light or oil lamp—the latter being arranged with screens operating to expose the proper danger signal. To avoid unnecessary stops or slowdowns at a crossing, a signal operating with the highway protection device is sometimes placed to indicate to the motorman whether or not the crossing device has operated. Such a signal is commonly arranged to indicate "danger" normally and "clear" when the crossing device is operating.

Crossing protection signals may be operated by any of the means used for ordinary block signals with the exception that in any particular installation the means employed must be such as not to interfere with the proper working of the block-signal system. A great many crossing protection devices have been developed. Following are a few typical schemes illustrative of methods employing differing principles.

Crossing Gate (of the Cook Railway Signal Co.). The gate-operating outfit consists of a motor-driven worm-gear mechanism so interconnected by means of a magnet clutch as to cause the gate arm to fall to the "danger" or horizontal position upon the cutting off of the current, and to cause the operating mechanism to raise the gate arm to the "clear" position upon the return of current. The fall of the gate arm to the "danger" position is not a sudden drop, as it is controlled by a band brake, which in turn is controlled by a governor. This brake and its governor connection are so constructed that they are adjustable, thus giving a quick or an extremely slow fall to the "danger" position. The gate mechanism is set into operation by the passage of the train over a track or trolley instrument located at a suitable distance from the crossing, and it is restored when the train passes another track or trolley instrument at the crossing.

Trolley Switch and Audible or Visible Signal. A "setting" switch is placed in the trolley wire at the approach to the crossing and a "restoring" switch is placed in the trolley wire at the crossing. The trolley wheel of a car passing the "setting" switch closes a momentary contact to energize the setting magnet of a relay in the crossing mechanism, causes its armature to be attracted and mechanically latched in position. This operation closes a permanent feed from trolley across contact points on the relay to the bell and through resistance to ground. Upon reaching the crossing, the trolley wheel on the car closes a momentary contact in the "restoring" switch, which, being connected to the restoring magnet of the relay, causes its armature to be attracted, which operation unlocks the mechanical latch above mentioned, allowing the armature of the setting magnet to fall by gravity and opening the trolley feed, thus restoring the signal to the inoperative condition. The circuits may be arranged to illuminate a danger sign at the crossing or for other lamp or light arrangement such as the use of red lights on the highway each side of the crossing or such other arrangement as will best suit the particular case.

Third Rail Contact. (Sedwick.) A section of third rail is laid on the side of the track opposite to that of the regular third rail which supplies the train propulsion current. When a car passes this point, the contact shoes of the car, being all four in parallel, make contact between the regular third rail and the above-noted insulated section on the other side of the track. There is a circuit from the insulated section through a relay and thence to ground. The relay has two sets of coils. When a car is approaching the crossing it passes over the section of rail which makes the contact so as to energize one pair of coils in the relay. The armature of the relay is then pulled over so as to make contact and establish a circuit from the regular third rail through a bank of five lamps to ground. An alarm bell is connected in shunt with one of these lamps. The lamps are lighted and the bell is rung until the car passes a second section of third rail which is beyond the crossing. In passing this section a circuit is established through the other pair of coils on the relay, which results in opening the alarm bell circuit and putting the signal out of operation until again energized by a car approaching the crossing.

Plunger Contactor. (Sauer and Johnson.) In this signal, the car wheels, in passing, depress the plunger of a track instrument, located close beside the rail. This plunger is held up by a stiff spring and can be depressed only by the car wheels. The car wheels, in depressing this plunger, operate a lever which pushes an armature up in a solenoid. This armature, when at the upplimit of its travel, makes contact between two fingers, thus completing the circuit from the trolley or third rail through the solenoid coil. The coil thus being energized, holds the plunger up of itself. The same circuit passes through the alarm bell and bank of lamps. The alarm bell circuit is broken by the passing of the car wheels over a similar track instrument on the other side of the crossing, which momentarily breaks the circuit and causes the solenoid of the track instrument on the other side of the crossing to let go.

Oscillator. (Protective Signal Manufacturing Co.) The oscillator is a rugged contacting device inclosed in a waterproof iron casing, so arranged that it may be fastened mechanically, in a rigid way, to the base of the running rail. It consists of a spring arm held at one end and carrying at the other end a magnetic coil in series with the line circuit connecting the oscillator and the signal mechanism at the crossing. Normally this contact is broken, but the movement or swing of the arm by vibration causes it to open the circuit momentarily at its outer end and thus start the operation of the crossing bell. The bell is kept ringing during the interval between the time that the train passes over the oscillator and the time when it reaches the crossing by means of a magnetic timer consisting of a ratchet wheel revolved by means of a magnetically operated pawl and retent, connected in series with the bell circuit. This is usually set to operate for 30 seconds after the oscillator has closed the line circuit.

Magneto Mechanical. (Hoeschen Manufacturing Co.) This apparatus operates independently of an external supply of electric current. One end of a lever pivoted near a rail extends under the rail. The other end carries the armature of a pair of induction coils having permanent magnets for cores. The passage of a train over the outer end of this lever depresses it, thus lifting the armature from the magnets. This induces a momentary electromotive force in the induction coils and the resulting current is conducted through line wires to the release magnets which control the bell motor at the crossing. The bell motor consists of a gear movement of three wheels used in connection with three motor springs. These springs are secured to the main driving shaft of the motor and are wound by a rod connected directly with a lever resting against the underside of the rail at a point opposite the motor. When the rail at that point is depressed by the wheel of each car of a passing train, a reciprocating motion of the winding rod (motor lever) is obtained, thus winding the springs and restoring the releasing lever which controls the motor. The connecting rods, extending from the winding rod to the pawl plates on which are carried the dogs for turning the ratchet wheel are arranged to wind the ratchet wheel on both the upward and downward stroke of the winding rod. The passing of one car will wind the ratchet more than 4 in. The motor gearing is so arranged that less than this amount of winding is needed to ring the bell for the passing of two following cars. The motor stores sufficient energy to ring the bell for about 100 cars before rewinding is necessary.

Automatic Train Stop

The necessity for an automatic device to stop a train increases as train speed is increased and as headway is shortened, becoming greatest where the possibility of failure to promptly see and obey a danger signal is greatest. Automatic train stops are generally so arranged that the train may "key by" in an emergency. That is, a member of the train crew may arrest the operation of the stop in order to let the train pass into the block protected. Aside from the location of regular stopping places, local conditions of traffic and right of way and the type and method of signaling in use, the climatic conditions under which the train stop is to operate must be given serious consideration in deciding upon the proper train stop for a required service.

The Joint Committee on Automatic Train Stops, American Railway Association, Nov., 1913, called attention tot he necessity of studying an automatic train control system with a view to avoiding the introduction of new elements of danger which might be greater than those which it is the purpose of the installation to overcome. This is because no automatic train control device, so far as known, can be universally applied without adding elements of danger in train operation. The following requisites of construction, installation and operation of an automatic train controlling system are from the report of that committee:

Failure of any essential part will cause the application of the brakes.

Proper operation under all conditions of speed, weather, wear, oscillation and shock.

A train traveling at a speed conforming to restrictions may pass a trip in the tripping condition without the brakes being applied.

Prevention of the release of brakes after application has been made until the train has been stopped or its speed reduced to a predetermined rate.

Stop or speed control accomplished within a predetermined distance.

Operation without interference with the application of the brakes by the motorman's valve and without a reduction in the efficiency of the brake system.

Operation without interference with fixed signals.

Union Switch and Signal Automatic Train Stop. Fig. 29 shows the type of automatic train stop used on the Pennsylvania Tunnel & Terminal installation in New York. This stop consists of a tripping arrangement on the roadway and a valve under the car which can be operated by the tripper to set the brakes. The tripper arm carrying the tripper, held in position by two helical springs, is mounted on a rocker arm and is operated in connection with the signal so that when the latter is at "clear" the tripper arm is depressed, by a solenoid or compressed air, against the ties and thus holds the tripper out of the path of the train mechanism. When, however, the signal is at "danger" the tripper arm takes the vertical position and upon being struck by the cushion spring on the train mechanism the tripper revolves about its axis on the tripper arm and operates the valve in the air brake system as indicated in the figure. The tripper is of light and flexible construction in order that it may not be broken by fast trains. Where weather or other conditions prevent satisfactory operation under the train the stop is placed overhead.

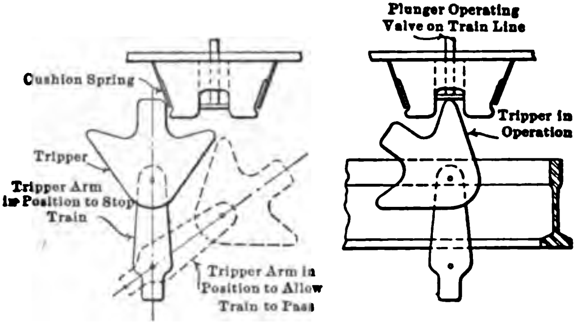

Cushion Spring
Tripper
Tripper Arm in Position to Stop Train
Tripper Arm in Position to Allow Train to Pass
Plunger Operating Valve on Train Line
Tripper in Operation

FIG. 29.—Automatic train stop, Pennsylvania tunnel.

Wilson and Wright Automatic Train Stop. The following is an outline of the train stop and its operation as used on the Washington Water Power Company's system: A pivoted metal arm projects out over the track at such a height when in a horizontal position as just to clear the roofs of the cars. This arm operates with the signal so that when the signal is at "danger" the arm is horizontal, and when the signal is at "clear" the arm is raised. Projecting above the roof of each motor car is a glass tube, sealed at the top and connected to the train air-brake system by a pipe at the bottom. When the automatic stop arm is in a horizontal position the glass tube on any car which passes the stop arm would be broken off and the air in the brake pipe would be released. This would automatically set the brakes and they could not be released until a new tube was substituted. In the event of failure of the signal and stop arm to clear, due to disarrangement of apparatus or circuits, means are provided for raising the stop arm by hand so as to permit a train to pass. When the stop has operated, the glass tube must be replaced and the air-brake system recharged before the train can proceed. This delay is of little importance except where the traffic is dense and the headway short. To provide for such a situation a long valve handle has been substituted for the glass tube. This handle operates a valve in the air-brake pipe.

Other Types of Automatic Train Stops. In the operation of other types of automatic train stops the control mechanism of the brakes on the train is influenced from the track by mechanical contact, electric circuit, mechanical contact and electric circuit, magnetic induction or Hertzian waves. Brief descriptions of several of these train stops may be found in the 1911 Proceedings of the American Electric Railway Engineering Association.

Suggested Clearances for Automatic Train Stop. Fig. 30 shows the limiting clearances for automatic train stop as suggested by the 1911 Committee on Heavy Electric Traction, A.E.R.E.A.

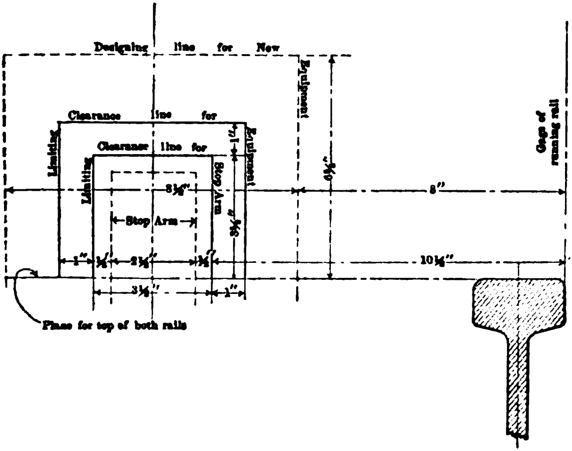

Designing line for New Equipment
Limiting Clearance line for Equipment
Limiting Clearance line for Stop Arm
Stop Arm
1"
6⅛"
8"
8⅛"
3⅛"
1"
⅛"
2⅛"
⅛"
10⅛"
3⅛"
1"
Gage of running rail
Plane for top of both rails

Fig. 30.—Clearances for automatic train stops.

Telephone

General Methods of Dispatching by Telephone. Where train dispatching is done by telephone, the telephone is either contained in a booth beside the track or it is carried on the train. In the latter case, connection with the line is made to terminals situated beside the track or by the connections provided for the cab signal. Where the telephone is the only method of signaling, the motorman or conductor of a train calls the dispatcher from whom he then receives his running orders. Where a dispatcher's signal system (see p. 805) in addition to the telephone is used, the dispatcher sets a signal at which the train stops and the crew communicates with the dispatcher. The motorman or conductor may receive the order and repeat it to the dispatcher directly or the motorman or conductor may receive the order, write it, meanwhile making a carbon copy which he gives to the other who reads it back to the dispatcher. The latter method insures the least chance for error in receiving the order.

Telephone Dispatching in City Operation. The following is a general outline of the system of telephone dispatching used in Rochester, N. Y., where, due to congestion, traffic handling is unusually complex: The chief dispatcher and several assistants are stationed at a special dispatching telephone switchboard located in the railway company's office building. This switchboard is connected by means of wires leased from the telephone company to telephone sets located at every line terminal and at main intersections. Telephone sets are also located at canal lift bridges, grade crossings and other points where delays are liable to occur. Each motorman is required to report immediately upon his arrival at a terminal. The act of taking the receiver off the hook at the terminal telephone immediately illuminates the line lamp at the dispatcher's switchboard. The dispatcher answers the call by pressing a key corresponding with the lamp, which places him in direct connection with the motorman. After receiving the call the dispatcher gives the motorman the time for his departure from that terminal and any special instructions that may be needed. The system in this way gives the dispatcher the exact location of all cars and advises him of any gaps in the service. In case of gaps he can easily order out "trippers" to fill in until service again becomes normal. The switchboard used at the dispatcher's office is made up in the form of a flat-top desk having mounted on it three turret-apparatus cabinets. Two turrets include straight dispatching line equipments, while the third is a combination dispatcher's and commercial board. During the rush hours three dispatchers are required, but ordinarily one or two are sufficient. Two of the turrets contain forty dispatching lines each, while the third carries twenty dispatching lines and also a multiple of sixty commercial lines appearing in the railway company's private branch exchange. This arrangement permits the night dispatcher, whose duties are light, to care for the commercial business, thereby eliminating a night operator for the commercial or regular private branch exchange board. Space is provided on the top of the desk for schedules, train sheets, etc. A tier of drawers accommodates past records, special schedules and a supply of dispatching stationery. The train sheets, arranged by train number and also in chronological order, are always before each dispatcher so that the whole traffic situation at any moment can be read at a glance. Not only is the best of service under normal operating conditions assured by this system, but a means for rapidly straightening out traffic tangles caused by delays is also provided. The system gives the railway company a permanent record of every train movement, late cars and times of accidents. There is also available in cases of court actions much exact testimony which would otherwise be based upon the inaccurate memory of witnesses. Furthermore, train crews promptly report trouble with cars and give many details whichthey would not bother to make out in written form.

Local Battery Telephones. Local battery telephones may be divided into two general classes, namely, series and bridging.

Series Telephone. (Fig. 31.) Series telephones give good service where there is only one telephone per line. They have been used where there are several telephones per line by connecting them in series with the line, but for such service bridging telephones are more satisfactory. The hook-switch, *H*, is shown in its raised position, so as to connect the receiver, *R*, and the secondary, *S*, in series in a circuit between the binding posts, *LL*, of the instrument; and at the same time the transmitter, *T*, the primary, *P*, of the induction coil and the battery, *B*, are connected in a local circuit by themselves. This is the condition for receiving or transmitting speech. When the hook is depressed, as when the telephone is not in use, the bell or ringer, *R'*, is connected across the binding posts, *LL*. This circuit would also include the generator, *G*, but for the fact that it is normally shunted out by the springs, *g* and *g'*. The contact between these springs is automatically opened, however, when the generator is operated and then there is current from the generator to the line through the bell, *R'*. The springs, *gg'*, form what is called an automatic shunt for the generator, their function being to remove the resistance of the generator armature from the circuit at all times save when the generator is in use.

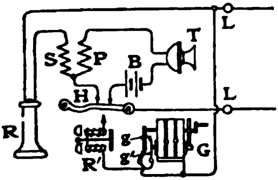


Fig. 31.—Series Telephone.

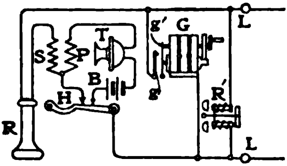


Fig. 32.—Bridging telephone.

Bridging Telephone. (Fig. 32.) Bridging telephones give good service where it is necessary to have several telephones per line. For this service these instruments are bridged across the line, that is, they are connected in parallel with each other. In the bridging telephone the arrangement of the receiver, induction coil, transmitter and battery is identical with that of the series telephone (Fig. 31). The ringer, however, is bridged permanently across the line and the generator is placed in a circuit across the line which is normally open, but which is closed automatically by the spring, *g'*, when the generator is operated.

Telephone Disturbance. Annoying inductive effects of adjacent alternating currents may be sufficiently reduced by transposing the telephone line wires relatively to each other so that the influences on one side of the line shall oppose and nearly equal the influences on the other.

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